A Study of the Framework of the Apple Tree and Its Relation to Longevity

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A Study of the Framework of the Apple Tree and Its Relation to Longevity

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OBJECT AND SCOPE OF STUDY

THE OBJECT of the study described herein has been to lengthen the productive life of the Illinois commercial apple orchard by improving the methods of heading the young tree. By "heading" is meant the training that the young tree receives in the orchard to place and regulate the development of its main branches. These and the trunk constitute its main framework, or head. Training is done by pruning.

That improvement in methods of heading fruit trees is desirable is evident from even a casual study of bearing apple orchards, where a certain proportion of the trees will be found breaking down from causes that can be traced directly to the way the young tree was trained. Other trees may be dying from causes not immediately attributable to the way the tree was headed; in such cases the type of head might be a contributory cause, but the relationship would need study.

A study of methods is necessary also because heading is difficult. The number and complexity of the problems that arise at this stage in the life of the tree can hardly be realized until one seriously attempts to train young trees with some such object in mind as the wide spacing of branches, the development of a framework of the modified central-leader type, or the maintenance of balance between branches. Many questions then present themselves. Should the young tree be pruned when it is transplanted? Should all varieties and individual trees be pruned to one type of head? How many framework branches should be developed? At what intervals should the framework branches leave the trunk? Is it better to thin out branches very early in the life of the tree, leaving only the permanent framework, or should the superfluous branches be left until some later stage? Contradictory answers have been given to many such questions, and the answers, whether in agreement or contradiction, are often stated without qualification. The contradictory, but nevertheless positive, nature of the answers is to be explained partly by a desire for definite answers to problems that are really complex. Whether the young tree should be cut back when it is transplanted, for example, is not a simple question that can always be answered with yes.

Since a primary principle in developing a method of training is that the method should, so far as possible, tend in itself to develop a durable tree, the authors, in their experimental work, have attempted to avoid any process in the early training of trees that would later develop faults needing correction, for correction is often difficult or impossible and always wasteful.

A further objective of the study was the development of a method that would be easy to explain and comprehend in all of its details; the method should be generally applicable, with little modification, to most varieties, and should not fail in certain seasons or on certain soil types. It should not require too much time in its execution and should not delay bearing materially.

As the study has progressed it has become more and more evident that conventional methods of training are uncertain and difficult; that they may bring about the premature death of the tree; and that methods by which trees might be trained more easily are being overlooked.

RELIANCE ON OBSERVATIONS AND HISTORICAL MATERIALS

The ideal test of a method of training would start with the young tree, follow it thru its various stages, and end with the dead tree. Productivity and longevity could then be related to recorded data on early condition and treatment. Such a procedure is, however, an impossibility. While one can start with the young tree and make certain observations and tests from young materials it is impossible for any one set of experimenters to observe all the later stages in the life of such plantings. As a substitute for following the same trees thru their complete life, it has been necessary to observe older trees and to attempt to relate their significant characteristics to the methods known to have been used in their training.

The historical development of commercial methods of heading, particularly within the state, and the potential longevity of the apple tree in Illinois have also been considered. For early methods of training within the state, correspondence with growers and their discussions and talks recorded in the *Transactions of the Illinois State Horticultural Society,* as well as the appearance of trees in commercial orchards, have been the source of information. While the conclusions at which the authors have arrived appear to them to be justified, it is obvious that the methods of observation that have of necessity been substituted for long-time controlled experiments leave the conclusions open to later modification.

EXTENT OF EXPERIMENTAL WORK

The authors have tested methods of heading with three successive plantings of nursery trees. The methods are described under each experiment. This part of the work was started in the spring of 1924 on the University farm at Urbana and has been continued up to the present time.

Demonstrations and tests of the methods suggested by these experiments were started in commercial orchards in 1926 by R. S. Marsh,[99] Extension Specialist in Horticulture. Long-time demonstrations, in which the results are watched from year to year, are in progress in thirty-two counties. Orchards in all parts of the state are included. Shallow, infertile, poorly drained clay soils, sandy soils, and various types of deeper and more fertile soils are represented. Some of the practices are being used and are under close observation in the student orchards at Urbana.

THE LIFE OF AN APPLE ORCHARD

The longer the potential life of the apple tree the greater is the benefit to be anticipated from observing any precaution at the start which may prolong its life. The benefit will also depend upon the extent to which the period of decline—that period in old age when the tree may still bear without being profitable—can be delayed. It is therefore well to ascertain first what the potential life of an apple orchard may be considered to be.

VARIATIONS RECORDED IN THE LITERATURE

Of most importance in the potential life of an apple orchard is the site where it is to be grown, for the environment of the tree upon which its length of life depends, cannot be transferred. To say, as Hartig[68] has said, that "the natural duration of a plant species is the period of time during which a plant is able to live without succumbing to the unfavorable external agencies in the soil and climate, or to the varied attacks of parasites and saprophitic organisms," is only another way of saying that the place where the plant grows determines its possible life. The statement applies as well to a horticultural plant such as an apple tree as it does to a natural species.

The environment of a tree is a complex of so many factors that no one loosely defined factor, such as a deep or shallow soil, a high or low temperature, or a heavy or scanty rainfall, can be expected to determine its potential life. The environment is really a sequence of complexes, each of which produces some effect upon the tree which, in turn, affects it in its relationship to its environment. If two sum-

mers could be exactly alike, their effects would necessarily be different if the two preceding spring seasons had differed. If one takes into consideration also the fact that the soil is not constant in its properties from year to year because of seasonal differences, and the further fact that the climate has a complex relationship to parasites, the undesirability of characterizing with constant and exact figures the effect of an environment upon the longevity of any plant becomes apparent. Artificial and additional sources of variation introduced into the environments of apple trees are differences in cultural treatment. This conception of extreme complexity and inconstancy in the environment is at variance with the practice of attempting to characterize a region on the basis of some limiting factor. This idea has been expressed very recently by Allen[4] as follows:

"Any natural environment is a resultant of the operation of an unknown number of factors, including a number of unknown factors. (By 'factor' I now mean any feature which is capable of recognition as a unit source of influence.) Some factors are constant in influence, some periodic, some sporadic, and some fluctuating. In addition, any individual organism is (immediately) a resultant of the operation of its own activities in a series of past environments. More remotely, it is a resultant of the activities of its hereditary chain thru many series of environments incident to the successive links.

"In consideration of the actual situation as outlined in the preceding paragraph, it seems somewhat presumptuous for finite minds to attempt to grasp the infinite details of permutations and combinations of influences responsible for any particular vital phenomenon, or for any particular sequence of vital phenomena. . . . .

"The term 'most significant variable' might properly replace the term 'limiting factor' in many discussions."

As might be expected, when estimates of the life of the apple tree have been made in restricted localities, the variation that has been found has usually been considerable, and there has been an equally great variation in the estimated period of productivity. Brierley[20] estimates the life of apple trees in Minnesota as 16.9 to 37.5 years, according to variety; these trees begin to bear when they are 6 or 8 years old, reach their maximum at 20, and gradually fail. According to Crane,[37] while the largest returns in New York are from orchards 40 to 55 years old, in West Virginia only 1 percent of the trees in two important counties are over 30 years old. In one of these counties the greatest profits are from trees 15 to 26 years old; in the other county trees from 15 to 22 years old are most profitable. In more mountainous regions of the state, trees are profitable at 40 to 50 years of age, and trees 75 to 100 years old can be found.

At Wooster, Ohio, the behavior of an orchard, as reported by

Ellenwood,[50] has been more constant. Yields increased from the seventeenth year, when the yields were first recorded, to the thirty-second. The varieties included were Wealthy, Oldenburg (Duchess), Transparent, Northern Spy, Jonathan, Baldwin, Rhode Island Greening, Rome, and Grimes. Yields in 1929, the thirty-seventh year from planting, were greater from all varieties except Baldwin and Oldenburg. The conclusion is drawn that in that section maximum production may be expected at 35 to 40 years from planting.

OPINIONS OF ILLINOIS FRUIT GROWERS

Reports of average longevity in other regions and of exceptionally long-lived trees outside of Illinois are interesting but of less significance to the Illinois grower than data concerning longevity in this state. To obtain local information the growers themselves were asked to reply to a series of questions. Information obtained in this way has an advantage over that obtained from a more exact study of a limited number of orchards in that it gives a better picture of the effect of the variety of conditions and cultural practices that occur in so extensive a territory as the state of Illinois. The questions asked were the following: How long do apple trees live? Between what ages are they profitable? What are some of the longest lived varieties? What are some of the shortest lived varieties? The growers were also asked to give their opinions as to the cause of death and the reasons the orchards became unprofitable. The answers were to be based upon the grower's own experience and upon observation in his locality. A part of the information is compiled in Table 1, in which each line represents an individual estimate.

The replies have been arranged in the table according to the location of the orchard—whether in the Ozark region, in south-central Illinois, or in western or northern Illinois. The Ozark section crosses the state near the extreme southern end. This part of Illinois is adapted by its location to the production of summer apples. Transparent and Duchess are grown extensively but not to the exclusion of later varieties. The upland soils of Johnson county, which have been described by Smith, Norton, and others,[127] are representative orchard soils of the region. The land is hilly, surface and subsurface drainage is good, but there has been serious erosion. The surface soil is shallow, invariably acid, and is very low in nitrogen and organic matter. On this soil plants suffer from drouth in hot dry summers.

By the south-central region is meant the extensive flat or slightly rolling area immediately north of the Ozark region, centering around Marion, Clay, and Richland counties. In 1900 only three counties

in the United States outranked Marion and Clay counties in total number of apple trees. These were Niagara county, New York, with 928,088 trees, Monroe county, New York, with 789,409 trees, and Howell county, Missouri, with 808,668 trees. Clay county, Illinois, had at that time 751,727 trees, and Marion county 795,188 trees. The surrounding counties were also heavily planted. There are still bearing orchards of these old trees in this region, but many orchards planted in the 1890's and 1900's have been neglected and finally removed. However, orcharding is still a leading industry.

The profiles of soils in the south-central region have been described by Norton and Smith[111] and Bauer and others.[11] The soils of Clay county are representative. They have been described by Hopkins and others[73] and Coffey[33]; the latter also describes the extensive planting of apples which took place in this region in the 1880's and 1890's. Subsurface drainage in this area is poor and the run-off of summer rainfall is high in spite of the slight slope. Many years the clay subsoil is repeatedly saturated during the late winter and early spring; in other years it remains almost dry. Nitrogen and organic matter are low, the surface soil is usually acid, but the soil at deeper levels is often alkaline. Ruth[122] found that most of the finer roots of apple trees in this soil lie very close to the surface.

The rest of the orchards have been grouped into the western and northern regions. Orchards from Calhoun to Bureau county are included. Altho the soils represented vary widely, they are all alike in a higher fertility and a more pervious subsoil as compared with the soils of the other two regions, and presumably at least they are alike in their much greater ability to supply water to the trees in dry weather. The latter two closely associated characteristics may be the "most significant variable" in the three regions, if so, the inclusion of so much territory in the last region is justified.

The data in Table 1 are believed to be quite reliable. In most cases the grower is deriving the largest part of his income from his apple crop, so that his estimate of the profitable age is likely to be accurate. Planting an orchard, or buying one already planted, and cutting it down when it is too old to produce are expensive operations which the grower is likely to remember.

Regional Longevity

The data in the third column of Table 1 would seem to indicate that there is little or no difference between one locality and another in the earliest age at which mature trees die, either in the degree of variability or in the averages. No difference is shown between the lon-

gevity of the long-lived varieties grown in the Ozarks and those grown in south-central Illinois, but in western and northern Illinois there is a decided increase in length of life.

TABLE 1.—LONGEVITY AND PROFITABLE AGES OF APPLE TREES IN ILLINOIS ORCHARDS

Orchard No.	Length of life of trees	Age between which trees are profitable
	Ozarks	
	years	*years*
1	30–40	10–35
2	30–60	12–40
3	15–50	10–35
4	35–40	12–35
5	30–40	10–25
6	30–50	12–35
7	35–40	10–30
8	40–50	10–35
9	30–50	12–30
10	20–30	10–20
11	30–40	10–25
	South-central Illinois	
12	35–40	6–30
13	25–40	15–25
14	20–35	12–25
15	40–60	10–60
16	30–40	10–30
17	25–45	14–40
18	40–60	14–35
19	–45	15–45
20	30–40	9–40
21	35–60	8–40
22	35–50	15–35
23	25–40	15–30
24	30–45	15–35
25	40–60	15–30
26	–50	–50
	Western Illinois	
27	20–50	20–40
28	40–50	12–35
29	35–75	15–45
30	30–50	9–25
31	25–60	20–50
32	30–	14–35
33	40–50	12–35
	Northern Illinois	
34	25–55	6–28
35	25–60	10–50
36	30–75	8–28
37	35–50	15–35
	Average	
Ozarks	30–45	11–31
South-central Illinois	32–47	12–37
Western and northern Illinois	31–58	13–36

In age of earliest profitable production, there is much less variation in the Ozark region than in the remainder of the state, where profitable production starts either considerably earlier or considerably later than in the Ozarks.

Greater longevity in western and northern Illinois would lead one to anticipate a corresponding difference in the age when trees become unprofitable. The final column in Table 1 indicates, however, that such a difference does not exist or that, if it does, the difference is not appreciable. There is a long unprofitable period of old age in commercial orchards in all sections. In the Ozark section the estimated interval between the profitable age and the death of the tree varies from 5 to 20 years; in south-central Illinois the extremes vary from no difference to 30 years. The owners of Orchards 15, 19, 20, and 26 believe that productivity can be maintained until the tree dies. The owner of Orchard 15, F. R. Landenberger, of Olney, says: "Whether a tree becomes unprofitable depends on its general care thruout its life. I have trees 40 years old in several varieties that I know are good for 10 years yet under proper care. It's all up to the orchardist and not to the tree." The owners of Orchards 19 and 20 express similar opinions. According to the owner of Orchard 26, John A. Garnier, of Newton, "trees in Illinois can be in a satisfactory bearing condition at the age of 50 years or more, depending on spraying, fertilizing, and pruning." He believes that the lack of proper handling of any of these operations could mean failure, and has seen "fairly thrifty orchards that should and no doubt would have lasted for many years, practically 100 percent dead within a very few years following a heavy cutting out of large branches." In the opinion of most of the growers in all parts of the state, however, there is a non-profitable interval before death. Reasons for belief in the possibility of prolonging profitable production have just been given; the reasons for believing the contrary will be stated after varietal differences in longevity have been considered.

Local Longevity

The figures in Table 1 are interesting also because of the variation which is expressed in every one of the estimates in each locality. In south-central Illinois, for example, the estimates of the oldest profitable age vary from 25 to 60 years, and of extreme age from 35 to 60. In the same locality estimates of the youngest profitable age range from 6 to 15 years, and of the age at which the first trees die, from 25 to 40 years.

One of the conclusions which can be derived from the growers' estimates is that the importance of variation within each region overshadows the importance of differences between regions, except in the total length of life and the correlated length of the old-age period after the period of profitable productivity. Among the factors which

may be taken into consideration in accounting for this high degree of local variability are soil differences within limited areas even as small as that occupied by one orchard. Such variations are shown in the maps of the Illinois soil experiment fields in all parts of the state,[11] where three or four soil types within comparable areas are not uncommon. R. S. Smith and E. A. Norton, of this Station, have shown by field examination that three recognized soil types exist within the 24-acre apple orchard at Olney, located on a very slightly sloping and apparently homogeneous site. In this orchard, and doubtless in many others, examination of the soil at tree intervals or even closer would be necessary to afford data for a soil map sufficiently detailed to locate each tree relative to recognized soil types. Less striking soil differences might also be important.

In addition there are differences in the distribution of rainfall within limited areas, which are undoubtedly of great significance; variations in the cultural practices of spraying, pruning, fertilizing, and cultivation; variations in planting, in stock, in planting distance, and in a multitude of other circumstances which may be operative locally within short distances.

Varietal Longevity

The answers to the questions dealing with varietal longevity are compiled in Table 2. Answers are separated according to locality. Varieties mentioned many times are definitely characterized. The Jonathan is named by twenty-nine of the thirty-seven growers as one of the long-lived varieties. Only one grower considers it a short-lived variety, and it is possible that it was not mentioned as a long-lived variety by the other seven growers because they did not grow it. Similarly, twenty-eight of the thirty-seven growers find that Grimes is one of the varieties that dies earliest, and this data can be taken without other evidence to show that the Grimes is a short-lived variety. Varieties mentioned only two or three times as short- or long-lived are not sufficiently characterized by this data, even if the reports agree. No variety is shown to be exceptionally long-lived in one section and exceptionally short-lived in another. The explanation to be inferred is that characteristic varietal susceptibilities or immunities are active thruout the state. It is also possible to infer that varietal characteristics which tend toward long life have the same relative effect thruout the state in spite of soil and climatic differences. The data in the questionnaire do not, of course, establish the absolute length of life of varieties in the various regions.

The minor part that longevity has played in the selection of com-

TABLE 2.—VARIETIES LISTED BY ILLINOIS GROWERS AS LONG- OR SHORT-LIVED
(Named more than once in 37 replies to questionnaire)

Variety	Location of grower's orchard		
	Ozark section of Illinois	South-central Illinois	Western or north-western Illinois
Akin	... ...	LL[1] ...	... ...
Ben Davis	L SSSS[1]	LL SSSSSSSS	... SSSSSSSSS
Black Twig	L ...	LL ...	L ...
Chenango	... S	... S	... ...
Delicious	... S	L S	LL ...
Duchess	... SS	... SSSS	L SSS
Early Harvest	... S	... ...	... S
Fameuse	... ...	... ...	LLL ...
Gano	... ...	... ...	... SSS
Grimes	... SSSSSSS	... SSSSSSSSSSSSS	... SSSSSSSSS
Ingram	... S	... ...	... S
Jonathan	LLLL S	LLLLLLLLLLLLLLL ...	LLLLLLLLLL S
Minkler	LL ...	LLLL ...	LLLL ...
Missouri Pippin	... S	... ...	... SS
Northern Spy	... ...	... ...	LL ...
Ralls	L ...	L ...	L ...
Red June	LL SS	... ...	... ...
Rome	LLL ...	LLLLLLL S	LL ...
Tolman	L ...	... ...	L ...
Transparent	L SSSSSS	... ...	... SSS
Wealthy	... ...	... SS	... S
Willow	LL ...	LL ...	LL S
Winesap	LLLLLLLL S	LLLLLL ...	LLLL ...
York Imperial	L S	LLLL ...	LL ...

[1]L = listed by one grower as long-lived; S = listed by one grower as short-lived.

mercial varieties can be inferred from data in this table. Four of the varieties named as short-lived, Ben Davis, Duchess, Grimes, and Transparent, are about as important commercially as any four long-lived varieties, such as Jonathan, Rome, Willow, and Winesap, that could be selected from the entire list.

Causes of Death

The two other questions upon which growers were asked to express an opinion were the cause of death and the reason the trees became unprofitable. Listed in the order of the number of times they were named, the causes of death were as follows (numbers in parentheses representing the number of times each disease or other cause of death was specifically named): Ben Davis, blister canker (15); Grimes, collar rot (14), neglect of fertilizing, pruning, cultivating, and spraying (9); blight of Ben Davis, Transparent, Willow, Jonathan, and Chenango (8); diseases and insects not named, which could probably be included with neglect (5); unfavorable soil, named by southern Illinois growers (5); root rot (4); heavy pruning (2); wood rot (2); bad crotches (3).

In its present connection this expression of opinion is interesting for several reasons. For one thing, the growers clearly attribute the death of Ben Davis and Grimes, two of the shortest lived varieties, to definite diseases, but they do not associate either disease with pruning. The control of blister canker depends, according to a recent publication by Anderson,[5] upon proper heading and the care of wounds in the early life of the orchard, precautions which will assure the orchardist of trees that are free from the disease. He finds that trees of the central-leader type are much freer from cankers than trees of the vase-shaped type. The difference he attributes to well-distributed lateral growths in the central-leader tree and to long bare spaces along the main branches in the vase-shaped tree.

Pruning may also bear a relationship to collar rot. As the result of field observation, Grossenbacher[64] recommends low heads for varieties of fruit trees subject to collar rot, a disease apparently due to growth of new tissues late in the season and injury to these immature tissues during the winter.

Late growth is favored by a cessation of growth in the summer which occurs frequently in southern Illinois orchards. According to Forsaith,[57] secondary annual rings are by no means uncommon in forest trees and are to be attributed to some abnormal ecological factor which, coming after the summer wood has started to develop, is suffi-

ciently severe to cause a temporary paralysis of the cambium. An interruption of this type may be brought about by fire, drouth, prolonged wetting, prolonged cold, prolonged heat, or defoliation. Subsequent to such a midseason cessation of cell division and the return of a more favorable environment, a new but narrow band of spring wood is laid down which in its turn is followed by the differentiation of a thin band of summer-wood cells.

Bradford[19] thinks that late growth and immaturity in apple wood may arise from a resumption of growth after hot dry summer weather. The trunks of apple trees in southern Illinois invariably show a considerably greater number of rings than they would if only one were formed per year, which can be attributed at least partly to the frequency of drouth.

Knight[85] compares the growth of the trunk of a young apple tree below a lateral to a wave flowing vertically downward, but overflowing to the sides and upward as its volume increases. In early June the new thickening forms a crescent on one side of the old xylem. The region away from the lateral is thus the last to expand. Cessation and recommencement of growth might be more likely at this point than nearer the lateral. In old apple trees this relationship may not always hold and, at any rate, is probably variable in degree.

A study of weather records in Illinois by Ruth[120] shows that long dry periods in the summer are the rule. Soil investigations by Ruth[120] also show that during these periods the water content of the soil is seriously depleted. It does not seem likely that the effect of conditions presumably so favorable to second growth could be entirely neutralized by low heading. Recent observations (1930) in the University orchard at Olney by the writers show that Grimes collar rot is common below heads 1½ to 2½ feet high. The injured areas seem to bear no constant relationship to the main framework branches. The time when the growth of wood at the crown occurs may nevertheless depend upon the type of head, in which case pruning, especially training the young tree, could hardly fail to be important, even tho the relationship might be so complex and so variable in its final effect that it would not be apparent from a more or less casual examination of injured and uninjured trees.

Root rot, named as a common cause of death by four growers, usually follows injury to the trunk, according to the numerous unreported field observations of Anderson. Ordinarily, at least, it does not seem to be the primary cause of the death of the tree. Fig. 1 illustrates an injury of this type. In this case the southwest side of the trunk has been injured by "sun scald"; following this, the roots on the

southwest side of the tree have died, permitting the tree to tip to the northeast. The amount of this type of "root rot," when sun scald is the primary cause, may possibly be decreased by starting the young tree with a low head with strong framework branches to the south and west.

Bad crotches, named by only three growers as a probable cause of death or unprofitableness, are definitely attributable to improper training. The relation of wood rot, named by two growers, to improper

FIG. 1.—TREE INJURED BY ROOT ROT
The southwest side of the trunk has been injured by "sun scald." The roots on the injured side have died, causing the tree to tip toward the northeast.

heading will be discussed later. One quotation, from the reply of W. S. Perrine of Centralia, is especially interesting in this connection: "Poorly formed heads cause trees to become unprofitable and eventually bring about their death. There are too many large limbs in the old framework. The removal of part of them starts decay; an over-crop then causes breakage. A proper framework and judicious annual pruning will greatly lengthen the life of apple trees, even in this section, where soil conditions are not conducive to long life."

Blight and neglect, which many growers advanced as a cause of death, can be connected with the type of framework only in a very general way, if at all. It is also a question whether neglect precedes

or follows the cessation of profitable productivity, for where trees are recognized as unprofitable, they are often neglected.

Why Trees Become Unprofitable

Finally, in answering the important question of why old trees become unprofitable, growers usually made no clear distinction between the causes of unprofitableness and those of death. Only eight gave the small size of the fruit produced by old trees as a reason contributing to unprofitableness, and only three growers mentioned the decreasing vigor of old trees. Alternation was named once, and the difficulty of spraying old trees was mentioned three times. One can assume that the last two conditions are more common than the direct replies would indicate.

ATTEMPTS TO EXPLAIN OLD AGE

Attempts have been made to explain old age by the developmental history of the tree itself. It was the opinion of Hartig[68] that the reduction and final cessation of growth in height of the tree, after the attainment of a certain maximum, should be ascribed to interference with nutrition and in all probability specifically to the fact that forces which conduct water and nutrient materials to the highest buds of the tree are limited in their action. Sooner or later, depending upon the plant, these forces would no longer suffice for the continuation of its growth in height. Also, the older the tree the more numerous would be the wounds thru which parasites and saprophytes would enter, and the slower would be the healing of wounds because of slower wood growth. He also thought that an increasing density of the soil as the tree grew older might be a factor, and that nutrient materials in the soil might become exhausted.

These hypotheses express something of the difficulty and complexity of the problem and the number of factors that probably enter into it. According to the cohesion theory of Dixon,[43, 44] the water lost in transpiration sets up a tension or suction in the water columns which is transmitted to the roots, and thru the external cells to the absorbing walls of the epidermis. The ascent of water to the tops of high trees depends upon the cohesion of the water within the conducting channels. Because a column of water within the plant is not broken when the strain balances the pressure exerted upon it by the atmosphere, it is possible for water in trees to be drawn to great heights.

Recent research by other investigators, particularly Huber[80] and Farmer,[56] on the resistance of the wood to the passage of water, has confirmed this theory in a detail which needed investigation. These investigations have shown that the force needed to draw water to the

top of the tree is not unduly increased by the friction produced in the greater lengths of wood thru which the water must pass. The increase amounts, according to Huber,[80] to about .2 to .4 atmosphere per meter. This difference is exactly in proportion to the difference in tractive force which Ursprung and Blum[137] previously found existed in upper and lower leaves of the beech. Except for the variability dependent upon the species and the age of the tree, the height of the trunk, and conditions in the environment, which are still to be studied experimentally, Huber[81] believes that in general it can be said that the differences in tractive force existing between leaf cells and root cells are sufficient to explain quantitatively the movement of water.

One can scarcely assume, however, that the tractive force is or can be increased indefinitely, or even beyond a rather low point for the species and variety, without producing marked effects upon the growth of the cell itself or upon the growth of adjacent parts. As Huber[79] points out, one of the conditions of old age in older parts of the tree is conceivably a reduction in the permeability of the protoplasmic membranes, resulting from the dehydration of protoplasmic colloids by a lack of water. Nutritive conditions within the old plant are very different from those within the young plant, as Kraus and Kraybill[89] have shown, but this can hardly be called a cause, in preference to an effect, of old age. As Pearl[113] and Weber[141] have pointed out in their reviews of the literature on senescence, it is likely that conditions of old age have been taken for causes. The soil in an orchard does not become denser as the tree grows older, nor does its fertility become exhausted.

Wounds.—Commercial fruit growers in the state have always looked upon wounds as a serious source of danger to the life of the tree, and a few of them have urged the use of training practices designed to avoid wounding the tree severely at a later time. The following statement of Buckman[24] is interesting:

"Many trees are killed yearly by cutting off large limbs. No limbs, except dead ones, should be taken off that are larger than two inches in diameter, and if I should say one inch, this would be the truth better still, but it would miss the customary practice, and even my own, by a mile and a half."

S. N. Black,[15] another of the earlier Illinois growers, advocated pinching back young shoots and disbudding because he thought that it "would wholly obviate cutting off large limbs and give at the same time a perfectly shaped and healthy tree."

Early horticultural writers also considered large wounds dangerous, and one of them, Bordley,[18] advised, in 1801, pruning in the nursery

in the year before transplanting with the specific purpose of avoiding wounds.

Among experiment station workers, Horne[74] considers that wood-rotting fungi, entering thru pruning wounds, are a serious factor in shortening the life of apple trees and decreasing production in California. He believes that numerous species attack apple wood in that state and that summer pinching and training would make it possible to reduce the severity of winter pruning materially. He strongly emphasizes the importance of training the tree as early as possible to a permanent head to avoid making large cuts later. Fagan and Anthony[55] conclude that pruning cuts are an important cause of the breakage of branches just coming into bearing thru the introduction of wood rots (Fig. 21). Marshall[100] advocates careful training when the tree is young if durability is desired. Howe[77] states that in New York decay often sets in in the exposed wood left in pruning.

A fact which seems to justify training the young tree in such a way that large limbs will not need cutting out later is the particular susceptibility to fungous invasion of old trees, of trees lacking vigor, and of large wounds. Solotaroff[128] says that the time it takes a pruning wound to heal depends upon its size and upon the rapidity of the growth of the tree, as well as upon the species. Bailey[8] brings out the fact that wounds on strong limbs, especially those that are vertical or ascending, heal best. Brierley[21] finds that wounds in weak young trees do not heal rapidly, and that even small wounds become infected in old trees if the branch lacks vigor.

Fungi.—Reports of serious damage to apple wood from definitely identified wood-rotting fungi have come from states in various parts of the country. According to Dodge,[45] forms of *Polyporus* are beyond doubt the main cause limiting the life of the apple tree in Maine; acting as saprophytes, they destroy the heartwood, so that the larger branches, and finally the trunks, are broken down mechanically. Weir[142] finds that *Fomes fomentarius* is parasitic on certain varieties in Montana, but not on others. Wilson[145] attributes the entrance of wood-destroying fungi in North Carolina to a preliminary invasion of black rot, to which, he says, there are varietal differences in susceptibility. Cardinell[27] found a fungus, identified as *Irpex tulipifera,* dormant in the heartwood of young winter-injured apple trees in Missouri. This fungus invaded healthy tissue exposed by pruning and prevented the healing of pruning wounds.

In Illinois the sapwood does not seem, as a rule at least, to be actively parasitized by any fungus except blister canker (*Nummularia*

discreta), which confines its activities almost entirely to Ben Davis. The mechanical weakening and loss of older branches appears to be the most serious effect of other wood-destroying fungi. Cross-sections of the trunks in orchards cut down because they are no longer profitable are almost always sound. In trunks of very old trees the wood may be decayed, and much of the heartwood may be gone. This fact can be interpreted as an indication that the conducting tissue has been resistant to invasion for a considerable period. That invasion of the sapwood is rarely, if ever, a serious factor in the death of apple trees in Illinois, except by blister canker, is also the conclusion of H. W. Anderson (unpublished observations).

Aside from the weakening of larger branches by the decay of heartwood which often follows severe wounding, heavy pruning cuts frequently result in the growth of shelf-fungi in the remaining large branches. It is likely that branches in which such growth occurs have been winter-injured. In this case winter injury is the direct cause, and pruning is the indirect cause, of death. This relationship was brought out in a striking way at Urbana in a pruning experiment in which a large number of Duchess and Wealthy trees were used. The various treatments were replicated four to six times. Ninety of 170 heavily pruned trees were so badly damaged along the trunks and in the crotches by winter injury in 1929-30 that most of them will die. None of the 220 lightly pruned, none of the 225 moderately pruned, and none of the 210 unpruned trees was visibly injured. The experiment was started in 1924, when the trees were six years old, and has been continued up to the present with about the same amount of pruning every year, so that the effect is possibly cumulative rather than the result of the pruning in the preceding March. A similar effect of pruning has been reported by Chandler.[28]

There is also the possibility that large pruning wounds bring about, without decay, the death of tissues that would otherwise remain conductive. This problem is now under investigation in this state.

Senescence.—If senescence in the tree is defined as a decreased rate of growth of the individual as a whole, pruning can be looked upon as a contributory cause of old age if winter injury or mechanical weakening of the tree results, since it reduces the growth rate as measured by increase in trunk diameter. As Weber[141] points out, old age is dependent upon undernourishment of the growing points or some other disharmony within the tree and is first shown by a decrease in the annual rate of thickening of the trunks.

That trees and plants in general actually decrease in growth rate

after a certain age has been shown repeatedly. According to Somerville,[129] the Scots Pine in a good locality will grow annually in height about 12 inches during the first ten years. For the next ten years, the average annual height-growth will be about 20 inches, followed by 18 inches, 13 inches, and 11 inches in the succeeding ten-year periods, until, when it is one hundred years old, it gets taller to the extent of only an inch or two each year.

The typical change in the rate of formation of wood in the trunks of old apple trees is illustrated by the following measurements which start at the center of the cross-section of the trunk of an old apple tree from the Frank Dirksmeyer orchard in Calhoun county. The cross-section was made near the base of the trunk shown in Fig. 2. In the first five years the total width of new wood (five years' annual rings) was ¾ of an inch; the total wood formed in each succeeding five-year period was 1⅝, 1¾, 1¾, 1¾, 1⅝, 1$\frac{7}{16}$, 1$\frac{3}{16}$, 1$\frac{3}{16}$, 1$\frac{5}{16}$, 1$\frac{5}{16}$, 1$\frac{5}{16}$, ⅝, ½ inches, respectively. The last figure is the growth made from the sixty-fifth to the seventieth year. At the level where the section was made the trunk had been increasing in diameter most rapidly between the tenth and the twenty-fifth years, but from that time on the rate decreased. Between the sixtieth and seventieth years the actual volume of trunk wood added at that point was only a little over half that added in the ten preceding years.

There is a possibility that the conductivity per unit area of cross-section of sapwood in trees in the period of decline decreases accordingly. Furr,[58] however, finds that up to the age of ten years, stems on this basis are more efficient conductors than branches, and, according to Forsaith,[57] the variation in thickness of annual rings is due to variation in thickness of summer wood rather than in thickness of the more efficient spring wood. The fact that the transformation of sapwood to heartwood is the result of disuse (Record,[118] Knight[84]) is an additional reason for believing that a decrease in conductivity is not a cause of old age. Here again, evidently, this condition of old age cannot be described as a cause.

The numerous reasons for old age of trees advanced by Hartig[67, 68] do no more it seems than define the condition itself. Pfeffer[116] defines old age on the basis of the individual cell. Every somatic cell, and hence every adult organ, appears, so far as we know, to have a limited duration, so that leaves die after one or a few years, while the old parts of apically growing rhizomes and mosses continually die away. The long life of a tree is attained only by the continual formation of new wood and bark by the cambium, and these tissues may either die in a few years or may remain living for a hundred years. Death is

induced by internal causes during the normal progress of development. The conditions for ultimate death are in fact assured whenever a somatic cell commences to undergo differentiation. Automatic death, Pfeffer thinks, can probably be produced in various ways. In addition to those cells in which the final stages of development lead directly to death, others may exist which would be capable of unlimited life were it not that the vital activity of the cell causes it slowly to wear out

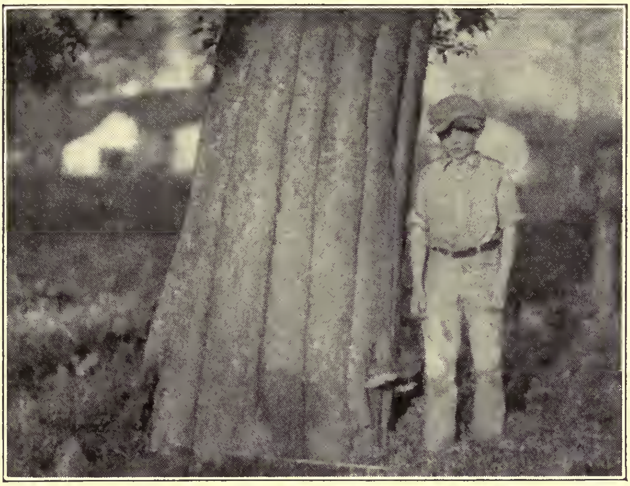

FIG. 2.—A SEVENTY-YEAR-OLD APPLE TREE

Decrease in growth rate of this apple tree, as indicated by ring measurements, set in at about the age of forty-five years. The tree was located in the Frank Dirksmeyer orchard in Calhoun county, Illinois.

and die. In such cases death would not ensue if the wear and tear could be completely repaired, but such a perfect power of repair does not seem to be possessed by the somatic cell even of the simplest vascular plants. Jost's definition of senescence[83] is similar. The tree has in the beginning a limited power of growth and finally reaches a maximum size. As a natural necessity, he says, there is a descending curve which finally ends in death. "Only the apical and intercalary meristematic regions, as also their youngest derivatives, remain alive in an old tree . . . Every cell which has lost its embryonic character dies after a longer or shorter period if it does not assume these characters anew."

Because it is possible for one-celled organisms to reproduce for thousands of generations simply by division,[146] the individual renewing

its youth with each division, while multicellular individuals differentiated into embryonic and permanent tissues die sooner or later, the opinion has been expressed that the death of the individual is the price of the differentiation that has made the higher organism possible. This has been the view of Minot,[107, 108] Child,[30] Conklin,[34] and Jennings,[82] as well as of Benecke and Jost,[12] Pfeffer,[115] and others. Unless some process of vegetative propagation is employed to generate a new individual, so that the embryonic nondifferentiated cells are made a part of a younger plant, the meristematic cells die, as well as those which have undergone differentiation. Conklin took the view that even in the oldest plants certain types of cells were still young enough to grow and divide. In his opinion, there was no reason to doubt that such cells were potentially immortal and, if saved from the general death of the organism as a whole, might live indefinitely. Jennings showed that in keeping the one-celled organism *Paramecium* alive and vigorous, sexual reproduction was not necessary. He found that sexual reproduction did not cause rejuvenescence, but was a dangerous ordeal, which in fact set back the average rate of reproduction. His conclusion was that sexual reproduction was not needed to prevent senescence.

For the continuous propagation of one-celled individuals Woodruff has shown that it is necessary to provide a continuous supply of suitable food and to remove the products of metabolism.[146] The death of somatic cells in higher organisms has been assigned to the failure of the higher organism to provide both of these conditions, that is, to the exhaustion of food and to the accumulation of the products of metabolism in cells which, on that account, become less and less capable of carrying on the processes necessary for their survival.

Metchnikoff[105] applied his theory, that senescence and death are due to toxins, to plants as well as to animals, declaring certain plants, for example, *Sequoia gigantica,* to be practically immortal since individuals of such species did not form toxins. Loeb[94] was inclined to follow Metchnikoff and in addition to suspect some structural shortcoming as the cause of "natural" death.

Benedict[13] assumes that the extremely complex colloidal states constituting protoplasm are progressively modified by the activities of life and the impact of external forces. He declares that "the wonder is not that protoplasm is subject to senile change, but that the change is so slow." In the opinion of Benedict permeability is reduced in old cells, altho all protoplasmic functions are involved.

Herzfeld and Klinger[70] thought that a decrease in permeability below an optimum for cell activity would be brought about by a deposition of particles within the meshes of the semipermeable protoplasmic

membrane. In consequence, they thought, the cell would be isolated and starved. It has, in fact, been shown that the rate at which several vital functions are carried on decreases as certain plant organs become older. It is well known that the most active respiration occurs during rapid growth. Leaves in process of expansion or fully expanded transpire more rapidly than at a later stage, according to Palladin,[112] Bergen,[14] and Koketsu.[87] Work dealing with this point has been reviewed recently by Maximov.[102] Willstätter and Stoll[144] have shown that the photosynthetic rate on the basis of the chlorophyl content is more rapid in young leaves than in old leaves, a difference which they attribute, however, to an enzyme which they believe decreases in amount as the leaf grows.

Lutman,[95] after a study of the potato plant, expressed the belief that old age is due to a lack of cell protein material, as shown in the chromatin and nucleoles, and an inability to assimilate protein fast enough to accumulate a store within the nucleus for division purposes. The accumulation of carbohydrates, he found, aided in staving off senescence, but in order to maintain the growth of a cell there had to be an accumulation of nitrogenous material, especially in the nuclei. He concluded that an abundance of nitrogenous material meant growth and the power of reproduction, and that in cells where the carbohydrate content was high, the ratio between the carbohydrate and protein content must be lowered before the cell really became young again. That protein was not to be found by microchemical tests in very old leaves which had turned yellow was observed by Hofmeister[72] as early as 1867 and confirmed by Molisch.[109] According to Meyer[106] the protein of the chloroplast and nucleus are used in the old leaf as a source of carbon for respiration; because of the low photosynthetic rate of the leaf in its old age, carbohydrates are no longer available.

Regardless of the ultimate process which may produce senescence, it is well to bring out again the fact that senescence is generally looked upon as the price of differentiation within the organism. Minot[107] described the life of a flowering plant as follows: "At first structure comes as a useful thing, increasing the usefulness of the part, then it goes too far and impairs usefulness, and at last a stage is reached in which no use is possible any longer—the thing is worthless."

That a vegetatively propagated variety can grow old, like an individual, is the conclusion of Benedict[13] from work with *Vitis vulpina, Vitis bicolor,* several cultivated varieties of grapes, and several kinds of trees, including fruit trees. He found that as the plant grows older the vein islets, or meshes formed in the leaves by the most minute veinlets, grow smaller. All the cells of the leaves of older plants ex-

cept the cells of the veinlets grow smaller, altho the total size of the leaf remains the same; the leaf respires more slowly and is less active in photosynthesis. The leaves of cuttings propagated from older seedling plants give more evidence of age, as measured by the size of the vein islets, than the leaves of cuttings propagated from younger plants, while older cultivated varieties of fruits give more evidence of age than younger varieties of the same fruits. Benedict does not believe that an unqualified denial of the possibility of somatic rejuvenescence is justified since certain specialized tissues have been made meristematic, but believes that rejuvenescence can be accomplished by sexual propagation.

Tellefsen[131] found that the size of vein islets in the leaves of *Salix nigra* decrease in size as the tree grows older, and that a similar relationship is maintained in the leaves of the watersprouts of young and old trees. Ensign,[52] however, found no difference of this kind in apogamous and sexually derived seedlings of *Citrus grandis.*

IMPORTANCE OF INFORMATION CONCERNING AGING PROCESS

If varieties of fruit trees as such really become old, the fact should be important not only in itself, since it would mean that the replacement of varieties would be necessary, but because it would imply that varieties should be propagated from embryonic tissues which had not been permitted to grow old, and should be propagated in such a way that they would not grow old during the process of propagation. Buds and tissues so situated in the tree and under such environmental conditions that they would not grow old should produce better trees than buds which were not so well situated, which would soon die out if left alone, and which are, in a word, senescent.

Crandall,[36] however, has shown that no such differences exist. He found no differences, for purposes of propagation, between large and small buds, between buds differently situated in the tree, or between robust and slender scions. Altho a retardation in growth was produced at first by the use of small buds it was overcome as the tree grew older. There was no evidence in Crandall's results of irreversible differences in embryonic tissue. If senescence existed within the bud it was overcome by propagation, altho not immediately. If a variety as a whole becomes senescent, the probabilities are that varietal senescence can be overcome in the same way, since there is no reason to assume that varietal senescence and bud senescence are essentially different.

Altho by providing suitable conditions the growth rate of an apple

tree can be increased at any stage, it does not appear that the old apple tree can be brought back as an entire individual into a condition even approximating an earlier stage. Individual branches can be made to grow rapidly by pruning, but the old tree in the Dirksmeyer orchard, referred to above, could not by any means be made to increase in size at the rate natural to it thirty or forty years ago. Because of the increasing susceptibility of the wood to fungous invasion as the individual grows older, it is impossible to renew the life of the old tree by renewing the life of a part, as might otherwise be done by severe pruning. Wounds and unfavorable environmental conditions are plainly contributing factors in an inevitable process, which varies in its rate with the variety and, in the apple tree, with the individual, because of the varying methods employed in propagation and because of propagation on a seedling root.

Because one-celled organisms multiply indefinitely when suitable food is provided and the products of metabolism are removed, one must assume that the old-age condition of the more complex organism is due to a change in structural relationships. It seems better to look upon changing structure as a cause of old age and death than to attribute it to a difference in the nitrogen content of embryonic tissue, or to a change in permeability, in the rate of respiration, transpiration, or some other function. Such changes are probably to be regarded as conditions and not causes of senescence.

It would seem that by proper care the long period of unprofitable old age in apple trees could be delayed, but that there would remain inevitably a long unprofitable period of decline. It is clear that the most practicable way of delaying death and prolonging the possibility of profitable production is the avoidance of large wounds, particularly in the later life of the tree.

HISTORICAL SURVEY OF AMERICAN PRACTICES USED IN HEADING

DEVIATIONS FROM EUROPEAN PRACTICES

With the exception of bending and tying branches away from the center of the tree, which is done occasionally, the very elaborate and detailed training common in Europe has not been approached in any way in America. Downing[46] in 1867 remarked that in the greater part of the United States, thanks to our favorable climate, European systems of training were unnecessary.

"In the place of long lines of brick wall and espalier rails, surrounding and dividing the fruit garden, all covered with carefully trained trees, we are proud to show the open orchard, and the borders in the fruit

garden filled with thrifty and productive standards . . . . three-fourths of the expense of a fruit garden here is rendered entirely useless."

According to Downing, interest in the type of training practiced abroad was confined to amateurs in the neighborhood of Boston.

CHANGES IN HEIGHT OF HEAD

The point of difficulty and of most interest to practical orchardists lay for a long period in securing strong trunks in the high-headed trees desired. The practice in 1817, according to Coxe,[35] was to form the heads high enough to allow a man and horse to pass under them in plowing. Hoffy[71] in 1841 advocated a height of 4 to 6 feet. Warder[140] in 1867 objected to certain inconsistencies of orchardists in their attempt to secure high heads, as follows:

"The large majority of purchasers at the nursery always select those trees which are most vigorous . . . . and then with mutilated roots, they probably omit cutting them back sufficiently. . . . Instead of demanding low heads, he asks for high ones . . . . so that he may at once calculate upon forming the head where he wants it, out of the reach of his horse."

Bailey[7] advised, as late as 1903, that "the head must be high enough to allow a team to work under it, and it must be easy of access for a man and beast. With properly trained teams," he said, "it is not necessary that the limbs be much above their heads."

However, high heading was not invariable. Wellhouse[143] in 1899 described the method used in Kansas in 1876 for starting the heads at one foot. In that state low heads were needed because of the strong sunshine. Other advantages of low heads had been recognized very early. The following quotation is from a book by Worlidge[147] written in 1687: "But the lower the Tree brancheth it self and spreads, the fairer and sooner will it attain to be a Tree, and the greater burthen will it bear of Fruit, and those better and larger." Recent work of Howe[78] shows that trees headed to 4 feet are inferior in size to trees headed low (20 inches), that the high-headed trees require more severe pruning up to six years, and that the ratio of root growth to top growth in high-headed trees is low. In the experiments of Crane[38] young low-headed trees have made more shoot growth, a larger gain in trunk diameter, and have a larger bearing area than high-headed trees.

The early practice in Illinois seems to have been variable, but to have favored low heading. The following short description by M. L. Dunlap,[49] a pioneer nurseryman and orchardist, of the methods that he used in 1864 is quoted verbatim:

"The first year after setting out the graft (root graft) the plant is allowed to grow without restraint, and will often make a growth of four feet. During the autumn (not when the wood is frozen) cut the tree back

to about twenty inches, and take off all side shoots. The tree will then form a uniform head. The second autumn the tree is pruned up to the main branches, which will be a foot to eighteen inches, leaving from three to five, according to the habit of the tree. The next year the tree will do to set in the orchard, though many are left two to three years longer. On putting in the orchard, the branches that would crowd each other are to be cut out to prevent this evil, and the last year's growth cut back to within three or four buds of the old wood. This will make the top correspond to the amount of roots, if the tree has been properly lifted. No further pruning will be required, only to keep down suckers at the base, cut away watersprouts, and an occasional branch that may rub against its fellows. . . . . The low head will shade the trunk."

According to the 1867 report of the "Committee Ad-Interim" of the Illinois State Horticultural Society,[1] the height of the head in Illinois varied from 1½ feet to 5 feet, while the method of pruning still remained a controverted question. The committee favored low heading because the trunks of trees in this state needed shade. That low heading was not practiced uniformly thruout the state for some time afterward is shown by the advice of G. W. Deland,[42] of Dixon, in 1899 to head trees 5 to 6 feet from the ground if one had a good windbreak, otherwise at 3 or 4 feet. Arthur Bryant,[23] of Princeton, advised 3½ or 4 feet in 1902.

It was not until the general adoption of spraying, when other arguments for low heads were also brought to the fore, that high heading was given up. Powell[117] spoke at the meeting of the Western New York Horticultural Society in 1905 in favor of low heading because of the necessity for spraying, "which is now as essential as cultivation," and for ease in picking and pruning. Cultivating machinery, he said, was becoming available for use under low-headed trees. Maynard,[103] in discussing the change in 1905 in a new book, "Successful Fruit Culture," advocated low heads for these reasons and to protect the trunk from the sun and wind; in the 1904 edition of an earlier book[104] he had given directions for heading trees at 6 feet.

The change is also discussed by Ballou[9] writing in 1907, and attributed to the same factors, of which the principal one was greater ease in spraying.

Bailey,[8] in "The Pruning-Book" in 1906, gave instructions for starting heads low in the orchard. Such advice was necessary because nursery trees were sometimes headed too high for those who preferred trees starting at a height of less than 3 feet. It was Bailey's opinion that the question of high or low heads was largely one of climate, methods of tillage to be employed, and kind of tree. In the East the error, he thought, was to train too high rather than too low; in regions where the trunks were apt to sun-scald, which included

nearly all regions outside of the Atlantic states, the bodies should be short. At the same time he pointed out the fact that high-headed trees do not necessarily make tall trees, because the framework branches tend to take a more horizontal direction.

CENTRAL-LEADER TYPE PREFERRED

Illustrations and directions given in the early literature on pruning apple trees show that several systems of training were advised. Bordley[18] in 1801 recommended treatment in the nursery previous to transplanting which would produce trees of the central-leader type, as did Coxe[35] in 1817 and Thacher[132] in 1822. Hovey[76] in 1853 illustrated trees of this type in "The Fruits of America." Downing[46] recommended that *"every fruit tree, grown in the open orchard or garden as a common standard, should be allowed to take its natural form, the whole efforts of the pruner going no further than to take out all weak and crowded branches."* On the other hand, Barry in the 1885 edition of "The Fruit Garden" stated that the management of "standard" orchard trees was well understood because of frequent publication, so that it needed little treatment. He then repeats exact directions, which he had given in earlier editions,[10] for producing vase-shaped trees. Similar instructions were given by Thomas[133] in 1868. Bailey[8] in 1906 stated that the "double story" tree, a type of central-leader tree in which the higher branches arise approximately at one point, altho it was impossible to secure it with all varieties, was to be preferred to the vase-shaped, or "one story" tree.

The statements of members of the Illinois State Horticultural Society in their transactions between 1864 and 1902 show that most growers at that time preferred to start their trees with a central leader. Their statements also indicate that the opposite system of training had been tried. Retaining a central leader is implied from the recommendation of M. L. Dunlap[49] in 1864, as quoted above, and was the expressed preference of the "Ad-Interim Committee" of 1867.[1] Arthur Bryant[22] in 1870 endorsed the opinion of P. J. Berckmans, of Augusta, Georgia, which he quoted, that "the pyramidal tree is the only one fitted for a young tree and for all climates. The old habit of pruning trees so as to give them a round and spreading form is very defective, and all rational cultivators condemn it." Mr. Bryant followed with this statement:

"I will only add that in my own practice during the last eight or ten years, I have found this mode of pruning more satisfactory than any other, and satisfactory in proportion to the faithfulness with which its theory was carried out. Some varieties, with only an annual pruning, are difficult to

make good pyramids of; but even an approximation of this form is an advantage as far as it goes. . . . the rotting cavities in the 'crotches' of our old apple trees are sufficient to condemn the old practice of cutting out the leader."

Grove Wright,[148] before a meeting of a section of the Society in 1873, demonstrated pruning in a way that, so far as the report of the meeting shows, was approved.

"Grove Wright exhibited two trees cut off in the nursery, and explained the best mode of pruning, viz., to so shorten in the young shoots as to prevent the formation of any forks, and *distribute the branches around a central stem,* from near the ground upward, so that the foliage will shade the trunk and distribute (balance) both foliage and fruit."

According to the statement of L. S. Pennington[114] in 1873, "the pyramidal, at least, as nearly so as the habit of the tree will admit, is the form that experience has most generally approved." O. B. Galusha[60] in 1880 was of the same opinion. He recommended intervals of about one foot between branches, and pruning in the nursery to prevent the formation of bad crotches. According to Benjamin Buckman[24] in 1893:

". . . . the perfect tree, which is seldom found, should have a main center stem of not less than five or six feet, from which, at proper and regular intervals, the side branches should grow. This head should be formed while the tree is young and the limbs small—the smaller the better."

H. M. Dunlap[47] in 1894 also preferred a tree with a stem running thru the center with branches diverging from it equally in all directions, leaving the main leader at intervals of 3 to 6 inches. Such a tree, he said, needs no pruning, and when grown will seldom split down or decay at the intersection of the branches with the trunk.

Mr. Bryant[23] again expressed his preference for the central-leader tree in 1902. In his opinion, "there should be a center shoot and not be more than three or four side branches." His method of training is stated as follows:

"I should shorten the leader a little and cut back the side branches, so that they will be subordinate to the leader, and try to keep them so. . . . . Should you receive a tree with sharp forks or badly branched, it is often the best plan to trim the tree up to a straight stem and start a new set of branches. But on no account cut off the top evenly, having it somewhat in the shape of a fan—as is often done. This would insure you a forked, badly shaped tree that will be almost sure to split down."

The vase-shaped type found little favor in Illinois. During the entire interval between 1864 and 1902 only one grower reported to the Society, or perhaps admitted, considering the prevalence of opinion to the contrary, training to the vase-shape type. This was C. C. Boggs[17]

who, in 1892, after stating that there was a wide diversity of opinion and that he had used the vase shape with three heavy branches, described his method of training as follows:

"My orchard has been pruned upon the system of cutting out the center stem and removing all but three limbs. These limbs are cut back to three or four inches in length the first year, so that the last bud on the limb shall be an outside bud. From this bud is to come the growth that you are to watch and care for and make one of the three great limbs of the tree."

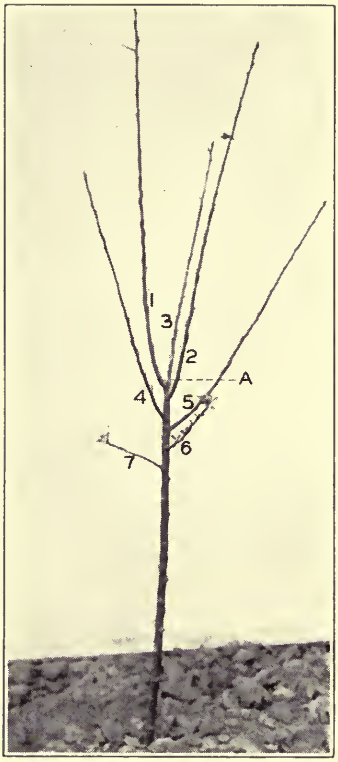

Fig. 3.—Result of Heading Back One-Year Tree

The whip was headed back at *A* in March, 1929. The buds just back of the cut were forced into growth in the summer of 1929, forming laterals 1 to 7.

This is the system that had been recommended by Barry,[10] Thomas,[133] and other of the earlier American horticulturists.

METHODS USED TO TRAIN ILLINOIS ORCHARDS NOW MATURE

Papers and discussions about training the tree came to an end in the State Horticultural Society in 1902, possibly because the members became more interested in other subjects, especially in spraying.

Judging by this lack of discussion, it is likely that training was given less consideration by newer members, and that there was a decrease in any uniformity in opinion, and still more in practice, that had been brought about by discussion. Correspondence and discussions with growers indicate, however, that when Illinois orchards now mature were planted the whip was always headed back at a height of 18 to 28 inches. This was almost always done in the nursery. The tree was permitted to make another year's growth where it stood, after which it was sold to the orchardist. A tree treated in this way was called a "two-year" tree, a term which distinguished it from an unbranched whip, which was called a "one-year" tree. At that time very few one-year trees were planted, and those that were were headed back at the height where they would have been cut back in the nursery. Up to this

point there was uniformity but, with the heading-back cut, uniformity disappeared. Some of the growers preferred to let their young trees entirely alone; others pruned them severely, in one way or another. If there was an accepted practice, it can perhaps be described, according to some of the older growers, about as follows: All but from three to five of the branches forced out by the heading-back cut were removed (Fig. 3). Those left were headed back in such a way that their cut ends outlined a cone, with the center branch longest and at the apex. It was assumed that such a procedure would develop a central-leader tree. In this first selection of young laterals, distribution around the trunk was taken into consideration, but angles, comparative vigor, and vertical spacing were largely disregarded. The angles between the more vertical laterals were necessarily often acute. It was assumed that the original set of laterals could be used to form the permanent framework, but with a maximum space of only 10 inches available between the height of 18 inches, where the orchardist may have left the lowest branch, and 28 inches, where he or the nurseryman may have cut back the whip, the average interval between each of four branches was only 3⅓ inches. It is likely that the original set of framework branches was usually crowded still more closely together, because the stronger branches, which the grower would not like to cut out, start much closer to the point where the whip was cut back. In every way this system of training, which was uniform at least in the detail of cutting back the whip, bore more resemblance to a style than to a logical plan designed to meet the desired end.

Some of the difficulties in the conventional method of training will be discussed in the following section. It will also be shown that with the application of these methods the opposite of the type of tree desired was produced.

DIFFICULTIES INVOLVED IN THE PRESENT CONVENTIONAL METHOD OF TRAINING

Cutting or heading back the one-year whip is still the general practice. It is the first step in the present conventional method of training, and is the most important, because the majority of the difficulties in training result from this cut. Whether necessary or not, its purposes are said to be to compensate for the loss of roots in transplanting, to make the trunk stocky, and to force branches from the trunk at the height where the lowest framework branches are wanted.

The practice almost invariably recommended is expressed by Alderman and Auchter[3] as follows: "The great majority of growers prefer

to start the head from 20 to 30 inches from the ground." The one-year whip, if that is used, should be cut back "at a point approximately four to six inches above the height at which the lowest branch is desired. Thus, if a 20-inch head is to be secured, the tree should be cut back to a height of 24 or 26 inches."

FIG. 4.—NARROW ANGLES CAUSE WEAK CROTCHES

Two vigorous, upright branches arising from the same point were allowed to remain when this tree was young. One of them should have been removed and the other utilized as a central leader. Narrow angles cause weak crotches which shorten the life of the tree.

If the one-year whip is left in the nursery, to be transplanted to the orchard as a two-year tree after another season's growth, it is customary to head it back in the nursery at the same height for the same purpose. The result has been shown in Fig. 3. Several problems are presented by a tree in this condition and a corresponding number of objects have to be kept in mind.

AVOIDING BAD FORKS

In the conventional method of training, two or three or even more vertical branches are developed just back of the cut, followed by less

vertical branches lower down. This result has been noted repeatedly by writers on the subject. Dahuron,[40] describing the effect in 1719, noted that in general the branch nearest the cut grew the most, the second

FIG. 5.—WEAKNESS OF CENTRAL-LEADER TREE

The highest branches of this four-year-old Grimes threaten to outgrow the lower ones. If this happens, the lower ones will eventually need to be removed.

more than the third, and so on down. As in the illustration (Fig. 3), the most vigorous branches are also the most nearly vertical. If more than one vertical branch is permitted to grow unpruned, one or more narrow-angled and therefore weak crotches, or forks, in the permanent framework will result (Fig. 4).

To prevent the formation of narrow angles, it may be best to remove entirely all vertical branches except the central leader. It is said that weak forks can be avoided by heading back one branch more

than the other. The orchardist cannot tell accurately, however, how much to head back to produce a definite result, and a general heading back may even decrease the angle of the lateral with the parent branch or trunk. Heading back unevenly to prevent the development of bad forks has been advocated frequently in horticultural literature and

FIG. 6.—CENTRAL LEADER CHOKED OUT BY SURROUNDING BRANCHES

In this tree the central leader has been removed because it was starved out by being completely surrounded at the same height by vigorous framework branches. A vertical separation of the framework branches would have prevented this. See also Fig. 15, page 563.

in the Illinois State Horticultural Society by some of its members, including, first, the "Ad-Interim Committee" of 1867.[1] The subject has recently been studied critically by MacDaniels,[96] who makes the same recommendation.

INSURING BALANCE IN THE FRAMEWORK

In general, heading back branches which promise, by their vertical direction and superior size, to outgrow the rest secures balance.

If a tree of the central-leader or modified central-leader type is to be developed, a tree in the condition shown in Fig. 3 must be pruned in such a way that none of the lower permanent branches will be outgrown by branches that will rise from the leader at a higher point (Fig. 5). On the other hand, it must be pruned so that the higher

FIG. 7.—TREE IMPROPERLY PRUNED FOR BALANCE

This photograph was taken one year after the pruning was done. The lateral framework branch was not cut back enough to subordinate it to the central leader. If the central leader had not been cut back also, proper balance would probably have been secured.

branches which will develop later in the center will not be "smothered out" by the growth of the lower branches (Fig. 6). To avoid one or the other of these two eventualities, very considerable foresight is required; not only the immediate effect, but the ultimate result, which will develop gradually and be manifested in its final form only after the tree is mature, must be predicted as accurately as possible. It is

safe to say that neither the condition shown in Fig. 5 or that shown in Fig. 6 was anticipated by the man who first pruned the tree. In deciding what cuts to make and how hard to cut to insure balance, the characteristics of the individual tree, especially its vigor, the number of lower framework branches left, their spacing, the tendency of the tree to upright growth, and other factors must be considered. That it is not a simple matter to keep the central leader dominant to exactly the right degree is shown by the conflicting advice of Alderman and Auchter[3] and Marshall, Cardinell, and Hootman[101] in recent publications. The former writers recommend the removal of branches developing from the central leader at a distance of less than 30 inches above the lower part of the framework. Marshall, Cardinell, and Hootman insist that the leader should be headed back to 18 to 20 inches, altho heading back much shorter, they say, "results in either a crowded framework or the saving of too few scaffold branches the succeeding year."

The problem of just how much to cut each branch to secure balance is further complicated by the fact, shown by Chandler[29] and observed by the writers (Fig. 7), that the heavier the young tree is cut as a whole, the greater must be the difference in the severity of cutting to secure a difference in growth.

PRUNING FOR DIRECTION

Securing a direction in the young branches more or less approaching the vertical is to be considered when the tree is young. The weaker and lower framework branches of young trees of spreading varieties are likely to droop, and to be outgrown. This is occasionally a reason for heading back. The resulting shoots arising just back of the cut take an upright direction like the shoots just back of the cut in Fig. 3. Heading back a weak horizontal shoot necessitates, in turn, a corresponding heading back of stronger parts of the tree to maintain balance. The succulent shoots produced in this way are easily blown about, and are likely to grow into the tree if located on the side of the tree toward the prevailing wind. Here, again, the procedure depends upon many factors.

HEADING BACK FOR STOCKINESS

Heading back to increase the diameter of the branch relative to its length is sometimes, but not always, thought to be necessary or desireable.

According to Barry,[10] writing in 1851, the diameter of a tree increases rapidly after heading back, so that when it recovers its former height it is two to three times as thick at its base as it was formerly

According to Alderman,[2] results on young trees on which experiments were made to test this point were not so clear-cut as could be desired, yet they indicated on the whole that heavy heading-in tends to thicken the branch more rapidly than light pruning, even as far down as the segment of branches produced four years previous.

In its effect upon stockiness, heading back must vary with the variety and the individual, and specifically with the number, position, and vigor of laterals produced by the pruned branches. Certain varieties, Grimes and Jonathan, for example, branch very freely. Laterals formed by such varieties are numerous, short, and well distributed. Other varieties, of which Delicious and Wealthy are examples, throw out only a few laterals which are confined to a space just back of the cut. These laterals are strong. (Fig. 3.) It is possible that heading back produces a different effect on the two types of varieties. There are two reasons for making this assumption; the first is the localized effect of lateral growth, and the second is the probable difference in the effects of long and short lateral growths.

Hoffy[71] in 1841 advised "encouraging the growth of every bud, especially at the lower part of the stem." Cooper, quoted by Thacher,[132] made the same recommendation previous to 1822.

The necessity of lateral growth for rapid thickening has been brought out again and again in the literature, some of which has been included in the summary by Tufts.[135] Chandler,[29] who found that rubbing off buds decreased growth, has suggested that there is a difference in the value of upper, rapidly growing and lower, slowly growing laterals in the growth of the stem and roots, the latter causing the greater growth. Hatton and Amos[69] also found that the removal, as they appeared, of lateral shoots along the trunk very definitely reduced the growth of this part of the tree, including the roots. This result Knight[85] interpreted on the basis of localized effect. Tukey[136] also found that heading back the laterals of two-year Cortland apple trees resulted in less trunk growth than thinning out laterals. Tukey's result can probably be explained in the same way as that reported by Hatton and Amos; heading back in all probability induced a growth of long laterals near the cuts (Fig. 3), while thinning out produced better distribution of growth. Taking into consideration all of the above facts, a varying influence upon stockiness is to be anticipated from heading back.

UNCERTAINTY IN SECURING RESULTS

The many uncertainties that are involved in pruning by the conventional method lead to uncertainty and lack of uniformity in the product. Good trees are, of necessity, a matter of chance in the con-

ventional method of training. Moreover, with so many factors to take into consideration, recommendations are difficult. Success in training, if the horticulturist or the commercial or amateur orchardist can acquire it, can come only after long and careful observation and personal experiment.

HISTORICAL OBJECTIONS TO THE CONVENTIONAL METHOD

In addition to the difficulties involved in the present conventional method of training apple trees, good reasons for trying other methods are the questionable premises upon which the present method is based and the radical changes that have been suggested by students of the subject. The fact that these suggested changes have not yet found favor can hardly be looked upon as an argument against them, because their feasibility has not in any case been disproved experimentally.

Heading back, the most important step in our conventional system of pruning, has not invariably been considered necessary. Bucknall,[25] an English horticulturist writing in 1797, is quoted by Chittenden[31] as having deprecated pruning in the season of planting. He preferred that it be done in the nursery the year before, after which the trees would not require pruning for some time and would grow more rapidly. Samuel Deane,[41] another Englishman writing in the same year, recommended thinning out laterals to balance the loss of roots. Bordley,[18] an American writing in 1801, advocated thinning out unwanted laterals in the nursery the year before they were to be transplanted to the orchard; if this were done, it would not be necessary to prune again for some time, and growth would be accelerated. Coxe,[35] an American, in 1817 also objected to heading back, saying:

"The tops of young trees should never be shortened [at planting], lest it should produce a growth of suckers: I would recommend in preference that they be thinned, if found too heavy: if the trees have been long out of the ground, and the roots have become shrivelled at the time of planting, the labour of pouring a pail full of water round each tree, will be amply repaid in the success it will ensure in their growth."

Thacher,[132] in *The American Orchardist,* published in 1822, recommended pruning in the nursery in preference to pruning after transplanting. "Thus managed," he said, "the trees will not require to be lopped for a considerable time; and as they will have no wounds open in the year when transplanted, their growth will be greatly promoted." He also thought that a young tree pruned in this way would come into bearing sooner and "continue in vigour for nearly double its common time." Harrison,[66] an early English horticulturist, expressed a some-

what similar opinion in 1823: "In respect to pruning the tops of young trees, I never do it at the time of planting (unless they are sickly) provided they are planted in the autumn, but if they be planted in the spring, and that season be far advanced, it will then be necessary."

Hoffy,[71] in a book published in Philadelphia in 1841, reported the successful transplanting of weak apple trees without pruning and advocated this practice. Bunyard[26] in England expressed the opinion in 1888 that "no apples should be pruned the first year of planting." Lansdell,[91] another English writer, reported in 1910 that judging from field tests and observation, fall-planted trees do best if unpruned. He believed that the balance between the roots and tops could be secured best by not pruning the top to correspond with the loss in roots, but by leaving the top entire, so that it would start out with a greater amount of leaf surface early in the season.

Chittenden,[31] working in England, reported in 1915 an experiment in which he compared the growth of pruned and unpruned trees. The trees were three years old. Some of them were on dwarf stock and the remainder on crab stock. They were planted in January and part of them were pruned in March. After this, all trees were pruned when dormant for the following three years. On the average, the unpruned check trees on crab stock grew nine percent less in the first summer, but in the third year those not pruned in the season of planting were the larger. The variation was great and, since the numbers were small, there seems to have been no significant difference.

That heading back the terminal shoot at transplanting is unnecessary and inadvisable was the experience of Goff,[62] who made the following statement in 1899:

"We have given it [cutting off the terminal bud] up in Wisconsin. The sentiment all seems to be in favor of leaving the terminal bud and I have set out a great number of trees that way myself and I find that they do not become top heavy. On the other hand I have seen an orchard planted in New York where the terminal bud was cut off at about five feet and those trees all branched below the terminal bud and the result was that there were about a dozen branches coming out like the spokes of a wheel right close together. What will result when the limbs are six inches in diameter? If we let the terminal bud grow, we have the branches distributed along the trunk six or eight inches apart; there are branches enough and they do not crowd each other."

Cranefield[39] described and illustrated this method of pruning in 1903. The terminal shoot was not pruned. Laterals of two-year trees were thinned out and very severely headed back.

H. M. Dunlap[47, 48] stated before the Illinois State Horticultural Society in 1894 and again in 1902 that the best results were to be

obtained from two-year trees by thinning out the laterals without heading back. Tukey[136] has recently reported the result of an experiment in heading in which the best Cortland apple trees were produced in this way. In the experiments of both Dunlap and Tukey only the best specimens were used. On this basis, the problem would resolve itself into working out methods for producing better two-year trees. To form low-headed trees when high-headed two-year trees were planted, Bailey[8] advised removing the laterals and pruning to a whip; except for heading back, this resembles the method advised by Goff[62] and Cranefield.[39]

These expressions of opinion and reports of observation and experimental work have had little, if any, effect upon practice, but they bring into question the necessity for the fundamental step in the conventional system of training the young tree, which is the severe heading-back cut. On the whole, there has been very little experimental work with other methods. The opinion that trees must be severely headed back in transplanting or in the nursery is still generally held.

EARLIER TESTS OF DISBUDDING AND PINCHING BACK TO LOCATE THE FRAMEWORK BRANCHES

In the commercial orchards of Illinois the young tree, until the results of the present experiment became apparent, was pruned only by heading back some of the branches and thinning out others, and all the pruning was done in the dormant season. Other possible methods of locating the framework of the young tree—which until recently have been almost completely disregarded—include disbudding, either in the winter or at the start of the growing season, and summer pruning, especially heading or pinching back the central leader while it is still growing.

DISBUDDING

As a part of a more elaborate system of training imported from Europe, Elliott[51] in 1859 stated that "at the commencement of spring growth, the manager has only to mark the swelling buds, preserving all those which he wishes developed for the formation of spurs, or for extending the leaders, and rubbing off all the rest." This he called "disbudding." This term seems to have priority over "debudding" and is therefore used by the writers in this bulletin.

Thomas,[133] another early authority, said that a tree could be molded into almost any desired shape by a proper use of the knife, or even by

the rubbing and pinching process. J. C. Utter,[138] an Illinois grower speaking in 1896, also recommended disbudding:

"The time to train a tree is when it is first planted by preventing a growth of too many limbs by pinching off the new buds or growths in the beginning, thereby avoiding the use of the saw later on."

Another Illinois horticulturist, S. N. Black,[15] made the following observation in 1899:

"Rubbing off the buds or young sprouts is the best pruning in the world, but it is hard to be always at the tree when the work should be done; or to be wise enough to see at once what should be rubbed off. Pinching and disbudding are the best methods of directing the growth and if perfectly done would wholly obviate the cutting of large limbs, and give at the same time a properly shaped and healthy tree."

Bailey[8] recommended going over whips which had been headed back at planting, and removing upper laterals as they started. This, he said, would force out buds farther down the trunks, thus producing the lower laterals which would become the lower framework branches. Truax[134] makes almost the same recommendation. He advocates pinching off all shoots not wanted in the scaffold from one-year whips which have been headed back, thereby avoiding their location all in one place by inducing buds lower down to send out shoots. Lewis[92] recommended rubbing off undesirable buds after heading back and removing or possibly suppressing undesirable branches during the succeeding month or two. Blake[16] believes that if undesirable buds are rubbed off before they make much growth the amount of shoot growth reduction may be of little or no consequence. He suggests this treatment where the trees have made a good start and are growing well. Except, however, for the work of Fagan[53, 54] and Fagan and Anthony[55] at the Pennsylvania Experiment Station, (1923, 1924, and 1928), the test of the Pennsylvania method of disbudding by Ruth and Kelley in 1924,[123] and their modification published in a preliminary way in 1929,[121, 124] this method of heading has been almost completely neglected experimentally.

SUMMER-TIPPING

Pinching back the growing shoot was recommended by Worlidge[147] as early as 1687:

"When your Graffs are grown half a yard high, those you find to shoot up in one Lance, pinch off their tender tops; which will prevent their mounting, and cause them to put forth side-branches. It's found to be the best way to guide a Tree either to grow, or extend itself in height, or cause it to spread in breadth; It gives not that wound to Trees that Incisions or Lances usually do; and besides, this may be done at that season, when the taking away of a Bud prevents the expense of Sap in wast[e], and diverts its course to others necessary to remain."

This very reasonable suggestion has not, so far as the writers are aware, been applied.

Barry[10] described pinching back as "a sort of anticipated pruning, practiced upon the young growing shoots." It was to be done when the tendency to undue or ill-proportioned growth was first observable, which would be from the time the young shoots were 2 or 3 inches long or upwards. Lewis[92] advocated summer heading back, comparable in severity to dormant pruning, in June or July if the tree had made a long terminal growth, cutting back to the point where it was desired to force out new laterals for the framework. Alderman and Auchter[3] believe that growing laterals can be pinched back during the summer to develop secondaries or to throw growth into other laterals wanted in the framework. Their opinions are not based on direct experiment; in their work in summer pruning they pruned heavily. Gardner[61] believed that early summer pruning comparable to dormant pruning had a place in training in Oregon.

Blake[16] has pointed out that a distinction must be made between pinching back growing laterals and thinning out branches during the summer, a difference which he says has been overlooked, resulting in considerable confusion with reference to the effects of summer pruning. He believes that the summer pinching of growing shoots does not lessen the vegetative development of the tree, altho it encourages late growth. He thinks it a desirable practice in New Jersey only when trees are making a very irregular growth, when it can be used to check the growth of the most vigorous branches.

Preliminary reports of pinching back the growing central leader to locate framework branches have been published by Ruth and Kelley from time to time, beginning with 1924.[123, 124] No other report of experiments designed to study this possibility and no other suggestion that summer pruning could be used to advantage in this way, except that of Worlidge,[147] have come to our attention.

TYPE AND EVOLUTION OF HEAD IN ILLINOIS COMMERCIAL ORCHARDS

The central-leader tree, it will be recalled, has proved the favorite of Illinois orchardists in discussions at meetings of the State Horticultural Society. At the same time, the method of training has been, and still is, to head back the whip with considerable severity with the purpose of "balancing the loss of roots" and "to locate the head." As a rule, the resulting crowded branches are thinned out, if particularly numerous, in the following dormant season, leaving the more upright

branches, the most nearly vertical of which is called the central leader. Those left are usually headed back. From the standpoint of future training it is important to know how often trees treated in this way have actually produced central leaders and to know the type of tree

FIG. 8.—AN OLD CENTRAL-LEADER TREE

True central-leader trees are rarely found in Illinois orchards. This tree is located in the orchard of Senator H. M. Dunlap, Savoy, Illinois. The original framework has been shaded out and removed.

produced when a central-leader tree has not resulted. It is also important to be familiar with general tendencies in all types of framework, because it may be possible to use such information when the young tree is first pruned.

Altho the terms "central-leader tree" and "modified central-leader tree" are commonly used by Illinois growers, there is no exact or common term to describe the tree which has no central leader. For reasons which will be given under the description of the vase-shaped

tree, it seems possible, however, to use the general term "vase-shaped" for such trees. For Illinois trees, therefore, only the three descriptive terms, "central-leader," "modified central-leader," and "vase-shaped," will be used. The changes which take place as the tree of each type matures, and the probable origin of each type, are discussed below.

CENTRAL-LEADER TREE

In this type a central leader runs to the top of the tree, or nearly to the top, giving rise at intervals to the main framework branches, all of which are smaller and less upright than the central leader (Fig. 8). As the tree grows, its branches are bent down by their own weight and that of the fruit. The least vigorous and most nearly horizontal branches are carried down first, and are shaded out by more vigorous branches directly above, which also become more horizontal. Weak, lower branches, often including branches meant to be permanent, are lost when the tree comes into bearing or soon after. At the same time, smaller, inner branches originating higher up along the trunk are shaded out. This process of elimination continues as the tree grows older. Some of the original framework branches are invariably outgrown, and there is a progressively wider and wider spacing of the entire main framework.

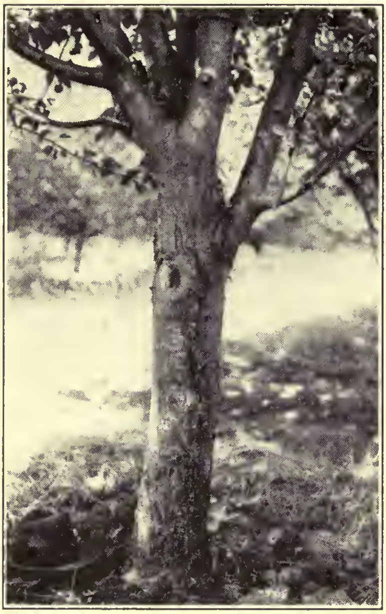

FIG. 9.—YOUNG CENTRAL-LEADER TREE

"Whorls" of branches often occur along the central leader. The lower groups are frequently shaded out, resulting in loss of much of the head.

Because of the tendency, which is especially strong in certain varieties even without pruning, for two or three strong laterals to develop annually from adjacent distal buds along the central leader, there are often successive groups or "whorls" of main branches in the young central-leader tree. As the tree ages there is a tendency for such grouping to disappear. At the same time, the loss of lower branches may result in materially raising

the height of the head, or the distance from the first framework branch to the ground (Fig. 9). This loss may be so extreme that a tree which was headed at 1½ or 2 feet may later in its life have a head 8 or 10 feet high. A typical young central-leader tree, allowing for very considerable variation among individuals, is represented by a Jonathan twenty years old with four framework branches about 2 feet above the ground, three branches at about 3 feet, two more at about 6 feet, two at about 8 feet, and two at 9 feet; or by a Duchess eleven

TABLE 3.—SPACING OF LOWER MAIN FRAMEWORK BRANCHES IN OLD CENTRAL-LEADER TREES

Height of branches above ground							
1st	2d	3d	4th	5th	6th	7th	8th
Jonathan—38 years old							
ft.	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*	*ft.*
2	4.5	5	7.5	9	9	11.5	11.5
1.5	2	3.5	4.5	6.5	7	10.5	11.5
3.5	4.5	5	7.5	8.5	9.5	14.5	15
2.5	3.5	10	10	12	13	13.5	....
1.5	1.5	2	5	6	6	7	7
Winesap—45 years old							
2.5	2.5	6	8.5	10.5	10.5	11	12.5
Willow—47 years old							
5	10	12	19	22	....	....	....
6	9	15	21	....	....	....	....
5	7	10	12	15	....	....	....
5	7	7	10	11	....	....	....
Ben Davis—30 years old							
3	3	6	7.5	8.5	10	....	....
4	4	7	8	10	12.5	....	....

years old with three branches at a height of about 1½ feet, three more at about 2½ feet, two more at about 6 feet, one at 9, one at 10, two at 11, and two at 12.

The spacing of the lower main branches in typical old central-leader trees is given in Table 3. Wounds made in removing lower main framework branches late in the life of trees of this type are often 8 or 10 inches in diameter.

VASE-SHAPED TREE

In the vase-shaped tree the main framework forms the outline of a tall vase. According to the description of Barry[10] and other early writers, there were three or four main branches leaving the trunk together at wide angles.

The characteristics of the framework which cannot vary, according

to the observations of the present writers, without excluding the individual from a logical classification as a vase-shaped tree, are the origin of the main branches within a very short space along the trunk and their approximate equality in size. Any considerable variation from these two criteria produces a tree which can usually be classified under the central-leader or the modified central-leader type. The ex-

FIG. 10.—LARGE SECONDARY FRAMEWORK BRANCHES EVENTUALLY SHADED OUT IN VASE-SHAPED TREES

Vase-shaped trees usually have fewer primary branches than has the young tree in *A*. The secondaries on this tree will be bent down, shaded out, and eventually removed, as they have been on the old vase-shaped Willow shown in *B*. The weight of the branches has caused the trunk of the Willow to split down. Long bare spaces along the main framework branches are common in old vase-shaped trees.

clusion of a tree from this classification because of narrow angles in the crotches or because there are more or fewer than three or four main branches is arbitrary, however, because no definite limit for angle or number of branches can be set. The tree with two main branches, for example, should still be called a "vase-shaped" tree. It would not be desirable to use some distinctive term like "double-headed" for such a tree, because the new term would not indicate other characteristics which it has in common with vase-shaped trees with three branches, which are, in fact, "triple-headed." The typical young tree described by early writers had wide angles in the crotches, but the method of training employed must often have produced trees

in which the angles became narrow as the tree grew (see Fig. 25). Crotch angles are often narrow in the trees in Illinois commercial orchards which the writers have classified under this type. The number of main branches is not always three or four, and altho the framework outlines the shape of a vase, it is often irregular.

As the result of counts made in several commercial orchards of the main branches of some of the commonest varieties, it was found that the most frequent number of main framework branches in old trees which can be included under the above description of the vase-shaped

TABLE 4.—DIRECTION OF PERMANENT BRANCHES AND OF BRANCHES TO BE REMOVED FROM ORIGINAL HEADS OF TEN 25-YEAR-OLD VASE-SHAPED GRIMES TREES

Tree	Inclination from vertical[1]	
	Permanent branches	Branches to be removed
	degrees	*degrees*
1	10, 25, 28	36, 70, 70
2	24, 20	37
3	0, 31, 35	None left
4	12, 45	59, 76, 46
5	21, 6	None left
6	7, 9	45, 38
7	3, 3, 25	None left
8	35, 4	54, 49
9	11, 38, 31	None left
10	9, 25	30, 44, 65

[1]This angle is formed by extending a line 6 inches outward along the upper side of the branch next to the crotch. Branches with the greater inclination from the vertical necessarily give rise to much of the outer part of the framework, even in the upper part of the tree.

type is three, followed by two, and then by four or more. When there are more than three large branches, the extra number usually do not arise directly from the trunk, but from a more central branch (Fig. 10, *A*). Each upright main framework branch in the vase-shaped tree gives rise, on the side away from the center of the tree, to laterals which correspond rather closely to the main framework branches of the central-leader tree. As the tree grows, the lower laterals are bent down and shaded out; those that are growing with the least vigor are lost first.

The elimination of the more horizontal outer branches as the tree grows older is illustrated in Table 4. In this table the main framework branches constituting the head of a few 25-year-old Grimes trees are also described in detail as to angle and probable survival or removal within a period of from one to ten years.

In vase-shaped trees forty to forty-five years old, bare spaces of 10 or 12 feet along the main branches are common (Fig. 10, *B*). As

the tree continues to bear there is a tendency for the upper ends of the main branches to be bent outward. If the branch is growing strongly, its upright direction is maintained by a vertical branch arising on the side toward the center of the tree. In very old trees, however, or in weak young trees, the upper ends of the main branches are permanently bent outward and downward and do not give rise to strong laterals to continue the vertical direction. This also occurs among the lower and weaker branches of trees which are, as a whole, growing vigorously, even if there is an open space above.

As in the central-leader tree, adjustment to a smaller and smaller number of main branches is continuous and progressive, and, as in the central-leader tree, the last branches to be removed are large. The present diameters of the branches to be removed from the trees decribed in Table 4 ranged from 2½ to 6 inches, and in trees forty years old wounds 8 inches or more in diameter are common.

MODIFIED CENTRAL-LEADER TREE

The ideal modified central-leader tree is like the vase-shaped tree except that there is an appreciable vertical separation of the main branches along a central leader. After giving rise to the highest branch the central leader loses its dominance and becomes a branch coordinate in size with the branches which have arisen from it. Trees of this type are almost never found in Illinois orchards.

ORIGIN AND FREQUENCY OF EACH TYPE IN COMMERCIAL ORCHARDS

The central-leader tree has probably developed from the young tree in the commercial orchard in two ways. In the first place, its development has often been due to the superior growth of one vertical shoot which resulted from heading back the whip and to subsequent light pruning or neglect. In the experimental work to be reported in this bulletin, heading back the whip severely has occasionally produced a tree in which one strong branch has tended to run away with the framework. On the other hand, the central-leader tree has sometimes been the result of an entire lack of pruning when the tree was set. A number of unpruned trees in one of the experimental plantings at the Illinois Station are developing in this way.

In an examination of commercial orchards, plantings of several acres of Delicious were found with very few or no central-leader trees, but there were scattered trees of the same variety in other orchards with well-developed central leaders. The vase-shaped trees had been given the conventional heading back and subsequent training.

The central-leader trees had evidently been neglected, and were probably replants.

The vase-shaped tree is the typical result of carrying out the conventional method of training, and results from the approximately equal growth of two or more of the strong laterals developed just back of the point where the whip was cut back. It is only rarely, according to the authors' observations, that the vase-shaped tree originates as a result of the suppression of the central leader by the growth of branches from lower points on the trunk, as in Fig. 6. Seventy-one of the ninety 12-year-old trees in the variety plantation at Urbana (two or three trees to a variety representing 35 varieties) are developing or have developed vase-shaped heads. The remaining nineteen have developed central leaders. The heads of all of these trees were started in the conventional manner.

In view of the general approval of the central-leader tree by Illinois growers, it would be expected that this type of tree would be common in Illinois commercial orchards. This, however, is not the case. In fourteen blocks of older trees examined in detail the percentage of central-leader trees was, on the average, 14.3 and varied from zero to a high extreme of 25. Almost all the remaining 85 percent were vase-shaped. Practically no trees belonged to the modified central-leader type. A very few trees were so irregular that they were not classified. Judging by this detailed examination and by observation in other orchards, the evidence is clear that the system of training employed in the state is producing vase-shaped trees, occasionally trees of the central-leader type, and almost never modified central-leader trees. Perhaps the Winsap tends, in spite of, or possibly because of, its drooping shape, to form a central-leader tree more commonly than other varieties, but there is, on the whole, little suggestion of varietal difference. Ben Davis, Winesap, Duchess, Grimes, and Delicious were all found forming no central-leader trees in some orchards and a fairly high proportion in others.

That so few modified central-leader trees are found, in spite of the fact that, in the past few years, several Illinois growers have thought that they were developing trees of this type, is not necessarily an indication that the modified central-leader tree cannot be grown commercially. It does show, however, that it is very unusual for this type to develop accidentally as does the central-leader tree, which develops fairly often in spite of a system tending strongly toward the vase-shaped type.

In the central-leader tree developing spontaneously after the customary early heading back, more severe pruning may be necessary at a

somewhat later period than in the vase-shaped tree produced by the same treatment, because the replacement of the original framework by other branches originating higher up from the central leader is often complete. In the vase-shaped tree only a part of the original framework can be lost (Fig. 10). Observation in Illinois commercial orchards leads to the conclusion that in the accidental evolution of most of the central-leader trees in this state wounding has been severe. Among the nineteen 12-year-old trees which have developed central leaders in the variety plantation just referred to, it will be necessary to remove within the next five years branches which now constitute on the average 40 percent of the tree.

Among the seventy-one trees in the variety orchard which have developed the vase-shaped type of head, eighteen will need no heavy pruning in the main framework in the immediate future. The average proportion of the present main framework which will need removal from the vase-shaped trees within the next five years, because of crowding or shading out, is estimated as only 22 percent.

TABLE 5.—NUMBER OF BRANCHES LEFT AND BRANCHES PREVIOUSLY REMOVED ALONG CENTRAL LEADERS OF INDIVIDUAL TREES IN BLOCK OF 38-YEAR-OLD JONATHANS

Present height of head in feet	Point of origin on trunk, measured from ground in feet							
	1, 2	3, 4	5, 6	7, 8	9, 10	11, 12	13, 14	15, 16
	Number of branches							
2............	1, *3*[1]	2, *3*	0	2	1	0	1	3
2............	1, *5*	1, *2*	1	1, *1*	2	2	...	...
1.5..........	2, *3*	2, *3*	1	1	1	1	2	...
3.5..........	*2*	2, *2*	1	2	1	0	1, *1*	3
2.5..........	1, *3*	1	0	0	2, *1*	1, *1*	2	...
2.5..........	1, *2*	1, *1*	1, *2*	1, *1*	1	1	1	...
1.5..........	1, *2*	1, *2*	1, *1*	3	2	4	1	...
2.5..........	2	2, *4*	0	1	1	1	...	...
2............	2, *1*	*2*	1, *1*	2	0	0	1	2

[1]Italics indicate additional branches previously removed. Only branches with a diameter of 3 inches or greater, as indicated by the diameter of the scar, are included.

In Table 5 the number of larger wounds along the trunks of the central-leader trees in a good commercial block of 38-year-old Jonathans is given, according to height above the ground.

On the average, about 4.4 branches, originating below a height of 5 feet, have been removed from the trees described in Table 5, after attaining a diameter of at least 3 inches. This is almost twice as many branches as are now left along the same part of the trunks. This amounts to removing two-thirds of the branches originating within 5 feet of the ground after they had become fairly large. So far, wounding has been less serious in the upper parts of these trees.

Only 10 of the 67 upper main framework branches (15 percent) have been pruned out, and removal will evidently be materially postponed because of wider spacing (on the average, one branch in every 15 inches compared with one in every 6.5 inches) and superior position. This orchard is exceptionally well cared for; in the average orchard with less prompt removal the wounds would have been larger.

The conclusion is that wounding is inevitable in either the vase-shaped tree or the central-leader tree if more than a very limited number of main branches is left at the start. The same conclusion probably holds for the modified central-leader tree also, which, with its coordinated branches and absence of a dominating central leader, resembles the vase-shaped tree. The vertical spacing in the framework, which is the characteristic by which the modified central-leader tree differs most from the vase-shaped tree, can hardly increase the number of branches that can be left permanently. The problem therefore arises as to the exact stage when the extra framework branches should be removed. The most reasonable alternative to removing extra branches completely when the main laterals are first formed would appear to be their partial suppression at that time. The relative desirability of the two procedures will be discussed later.

It is a very interesting and significant fact that the preponderance of opinion among both the growers and the experimenters has been that the number of branches should be limited at the start. The vase-shaped tree described by Barry[10] called for three branches, and Illinois orchardists have frequently described trees with three or four.[23] Horne[74] recommends early limitation with the specific purpose of avoiding severe wounding later. Lewis[92] preferred four or five branches to three, which he considered too few to rely upon. All four or five were to be located below the lowest heading-back cut, which was given the one-year tree 25 or 28 inches above the ground. Alderman and Auchter[3] advise leaving a total of only three or four of the laterals developed in the first two years, because five or six would crowd the framework later, altho the tree might look better at first. Similar recommendations advising a very small number of permanent branches have been given practically without exception.

TRUNK SPLITTING AND CREASING

A serious tree condition found in most orchards is the splitting down of the trunks of trees in the way illustrated in Figs. 11 and 12. The tree that splits down not only loses branches that should continue to bear, the part lost often comprizing a large part of the top,

but is particularly subject to the dangers consequent to wounding, which is especially severe in such a case.

In some commercial orchards almost no trees break down in this way; in others practically all of the trees of certain varieties seem to be approaching this condition. The proportion of trees that have been lost in old orchards thru trunk splitting cannot be estimated accurately, because after the trunk splits down the rest of the tree is usually taken out in a few years at most, leaving only a vacant space in the orchard. It is often possible to predict the loss of a tree from this cause, if there is actual evidence of initial trunk splitting. In one large block of 12-year-old Delicious trees in western Illinois there is visible separation, in at least one plane, in 24 of the 27 trees examined closely, and the proportion seems to be equally high in the rest of the block. The owner of this orchard has a tree of the same variety and of about the same age in his yard in town that gives no sign of splitting. Judging by the condition of the framework, this tree will never break down in the same way. It was pruned by the same orchardist, but the most casual examination shows that the head was started differently. For his large planting he was following the conventional method.

Many of the trunks in a large block of 41-year-old Willows in another orchard resemble the trunk illustrated in Fig. 10, *B*. This orchardist has another block a year or two older in which comparatively few trunks are splitting down. Here, too, a difference is to be seen in the way the trees in the two blocks were pruned in the first few years. It is plain that the tendency to split down varies not only from tree to tree but from block to block.

Splitting down does not necessarily result from the development of vertical ridges or ribs and grooves in the trunk, as illustrated in Fig. 13, altho the grooves, or depressions between the ridges, furnish the paths for cleavage. Trunks do not split down along a depression in which a knot has been left by the removal in some previous year of a main branch, doubtless because knots furnish resistance, as they do in forest trees (Roth[119]). In Fig. 13 the relationship of the branches and ridges can be seen easily; the latter have the appearance of continuations down the trunk of the branches above. They occur directly beneath the branches, and vary in size with the size of the branches.

RIDGING AND SPLITTING DISTINCT VARIETAL CHARACTERISTICS

Ridging and splitting are to a large extent varietal characteristics, and as such are not entirely correlated. The Willow, which splits down

FIG. 11.—CREASING AND TRUNK SEPARATION

Extremely narrow angles have prevented the building up of adequate crotch tissue in this 12-year-old Delicious.

FIG. 12.—AFTERMATH OF TRUNK SEPARATION

This 22-year-old Jonathan has lost a large part of its bearing surface, and the remainder of the tree will soon die.

FIG. 13.—VARIETY WHICH RIDGES HEAVILY

Grooves, such as those between the ridges in the above Willow, furnish paths for cleavage.

FIG. 14.—VARIETY WHICH RIDGES LIGHTLY

In general, varieties which ridge lightly, such as the Ben Davis shown above, are not apt to split.

(Fig. 10, *B*) more commonly than any other variety in this locality, except, possibly the Delicious, is also the variety which forms the heaviest ridges. The Delicious, on the other hand, develops light ridges, and often splits down long before ridging is at all pronounced. The Jonathan, Duchess, and Akin all form pronounced ridges, but Jonathan and Akin trees split down only rarely. The trunks of Ben Davis, Black Twig, Winesap, and Grimes, which form only light ridges and only in quite old trees, are still less likely to split (Fig. 14). Maiden Blush and Rome appear to be intermediate in their tendency to form ridges, but in their tendency to split down the Maiden Blush is intermediate, while the Rome behaves like the varieties which ridge the least.

Factors Influencing Radial Trunk Growth

One of the best descriptions of the ribbed trunk was published by Hoffy[71] in 1841:

"An interesting instance of the tendency of buds or branches to send down straight roots or woody fibers to the earth, and thus to increase the diameter of the main stem, may be seen in any old orchard, where the trunk of the tree consists of several large ridges, as if it was composed of sundry smaller stems fitted together around a common center. On looking up it will be seen that every ridge begins immediately at a large limb which has been sending down ligneous fibers in a direct line to the ground for many years. On tracing this great bundle of fibers downward, we shall find it terminating in a large root. Had this limb been cut off while young, neither this strong woody rib nor this large root would have been formed."

It is interesting to compare Hoffy's description with the following recent description of localized radial trunk growth and the relation of root and branch by MacDaniels and Curtis,[97] which summarizes the results of their own experimental work and earlier confirmatory evidence:

"The conception that growth of the vascular tissues is so largely determined by the coming together of food from the leaves and nutrients from the roots, and that these substances tend to move in straight lines parallel to the axes of the elements of the vascular tissues, is of value in interpreting the growth response to various cultural practices. For example, on this basis it is apparent that the width of the annual ring in any one section of the branches or the trunk of a fruit tree is dependent on the leaf surface anatomically attached to that section above, and the roots attached below. Thus, if the orchardist desires to build up a branch on the upper side, or promote the filling-in of a narrow crotch, it is important to leave foliage attached to those parts of the branch that are directly above the section to be strengthened."

Shaw[125] found a positive correlation in the size and number of the

main branches of apple trees and the size and number of the main roots. This correlation, altho obscure in many individual cases, was nevertheless to be observed if large numbers of trees were examined carefully. He found it more clearly defined in budded than in root-grafted trees. Shaw says that "the control of the bud or graft over the seedling root system is pronounced." Knight[85] describes trunk growth in the young apple tree as a wave flowing along a course vertically downward, but overflowing laterally and upward as its volume increases. The vertical dependence of branch and root has also been brought out by Knowlton[86] and Auchter,[6] who noted the responses to fertilizers applied under parts of trees.

Altho there can be no doubt of a localization of trunk growth under branches in older apple trees in the varieties which form the heaviest ridges, growth initiation in the trunk of the older tree does not necessarily progress downward from the branches, as it seems to in the very small trees with which Knight worked. The weight of evidence obtained with other kinds of trees as well as with apples is opposed to this idea. MacDougal[98] concludes from his measurements with the dendrograph that "no basis has been found in the Monterey pine for the present conception that the activity which is first visible in the buds gradually descends to the trunk and down the trunk to the base."

According to the recent summary by Lodewick[93] of the very voluminous literature on cambial activity in trees, the evidence to date with forest trees, including the evidence which he himself secured, is "generally in accord with earlier investigations that xylem elements are formed first on the one-year twigs, and that the growth impetus progresses gradually to the older portions of the crown (the crown in the sense of the forester, meaning the part bearing branches). Upon reaching the trunk or larger branches, growth becomes general over the aerial portions of the tree." If growth progresses rather regularly down the young branches of older trees, starting with the youngest twigs, the progress of growth initiation within such branches resembles the wave which Knight[85] describes as occurring along the trunk of the young tree. In growth initiation the trunk of the young tree and the young branch of the old tree are comparable, but the trunk of the young tree and the trunk of the old tree are not comparable.

Altho the initiation of growth over the major part of the older trunk does not appear to depend entirely upon proximity to branches, total radial growth seems to bear such a relationship when the food supply is limited. Thus Hartig[67] found that in overtopped pines and spruces between 20 and 30 years old the rings became thinner from

the branched top downwards and that in some cases as many as seven rings had been entirely omitted on the lower parts of the stems. Grossenbacher[65] found with apple trees that heavy pruning was capable of resulting in a decreasing thickness of the next annual ring toward the base of the trunk. Shreve[126] found that in a 38-year-old Monterey pine, which had reached a height of 65 feet, the greatest radial increase in a given year occurred generally in the upper half of the trunk, and most commonly within 15 to 20 feet of the top. The year of greatest growth, as shown in cross-sections made at various heights, was commonly found at or near the center of the trunk, and very rarely more than four rings from the center, which meant, of course, a continual shifting upward of the area of most active growth. In the apple tree a similar upward shift is indicated by the frequent occurrence in old trees of long main branches of almost uniform diameter from the base upward for a considerable distance, and by occasional old trunks which gradually decrease in diameter toward the ground.

The earlier literature on radial growth in trees was discussed at length by Grossenbacher[65] in 1916; this discussion was followed in 1928 by the brief review by Lodewick[93] already referred to.

NARROW CROTCH ANGLES FAVOR SPLITTING

That trunk splitting depends upon certain characteristics of the individual framework in addition to varietal peculiarities is implied whenever the advice is given to prevent the development of bad forks. By a bad fork, or even by a "fork," as the term has commonly been used, is meant a pair of branches of equal size separated by a narrow angle.

As Goff,[63] Alderman and Auchter,[3] and many other writers have said, forks in the trunk of the tree, dividing the wood into two nearly equal parts, are objectionable since one or the other part is very likely to split down under the weight of a heavy crop or in a storm. Advice to prevent this type of fork is commonly incorporated in directions for training. Its importance has been known to some, at least, of the Illinois growers for more than fifty years. O. B. Galusha,[59] at a meeting of the State Horticultural Society in 1873, advocated pinching off or shortening in branches that tended to form crotches or forks while the trees were still young, "as these would almost certainly split off when loaded with fruit." The same grower[60] in a later meeting advocated training for this purpose in the nursery. Other growers have advised the avoidance of forks from time to time.

Judging by the poor heads of mature trees in commercial orchards, one might conclude that the advice to avoid forks was not commonly

followed, but the situation might be explained on the alternative assumption that the method for preventing bad forks was at fault. The latter is a likely explanation if the main head is looked upon as a complex and unstable system of more or less numerous forks, each of

FIG. 15.—TWO BRANCHES FROM CENTRAL LEADER AT SAME HEIGHT

This fork, now strong, will be weakened by the death of the central leader, which has been starved by the two surrounding branches.

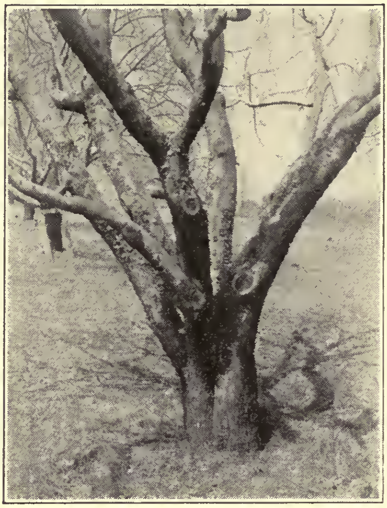

FIG. 16.—CROWDED HEAD INCREASES DANGER OF SPLITTING

Branches arising from near the same point on the trunk of this Jonathan form two nearly equal groups, increasing the danger of splitting.

which consists of two or more arms separated vertically and laterally by a variety of angles and intervals. If the main framework is thus considered as an association of temporarily correlated parts, the first object in a study of the head is necessarily a determination of the relationship of the parts to each other, some of which have already been considered in the description of the evolution of the vase-shaped and central-leader heads.

A closer study of forks in the main framework has shown, in fact, that the bad main fork cannot be fully defined as a single pair of large branches separated by a narrow angle; but that other factors enter. Maynard[104] observed in his book, "The Practical Fruit Grower," that young trees, as they came from the nursery, were of two types, one of which was much to be preferred to the other. The tree of the better type bore its laterals along a main axis, while in the other the branches came out at one point, and were likely to split

down later. It is probable that Maynard was looking at the latter type of head as a fork with several arms. In addition to preventing acute angles and equal forks MacDaniels[96] advises against permitting more than two scaffold branches to develop at one point, because the crowded condition prevents the wood of the main trunk from partly surrounding and supporting them (Fig. 15). Fagan and Anthony[55] advance as a reason for separating the main branches early, and thus avoiding the close head with three or more arms, the probability that in such a head undesirable grouping (Fig. 16) will occur, because several branches arising from nearly the same point on the trunk frequently form two nearly equal groups and create the same danger of splitting that we have with two equal branches.

RELATION BETWEEN ANGLE, SIZE OF BRANCH, AND TRUNK SEPARATION

That angle and size are both factors, but that the relation between size, angle, and trunk separation is not entirely simple, is brought out by the data in Table 6. The branch referred to in the table is always the lowest main branch if the tree has a central leader; if the framework is vase-shaped it is one of the main branches. The angle measured is the one between the branch and its neighbor. Trunk separation, where noted, was always clearly defined, and is interpreted as incipient splitting. Each measurement represents a single tree, and data from 106 trees are collected in the table.

In securing the data the absence of trunk creasing and creasing without visible separation were also recorded and are included in the table to bring out the relation between splitting and creasing.

The fact that narrow angles favor trunk splitting can be seen by comparing the angles of larger branches above trunks that have separated with branch angles above trunks of the same size that have not separated (Table 6). Except in the older block of Willows, splitting occurred only under narrow angles, and in most cases in the other blocks the angles under which splitting occurred were between 5 and 15 degrees. Such branches are almost parallel and vertical and, as the previous discussion shows, are the vigorous branches produced by heading back the whip. Narrow angles alone, however, do not invariably result in splitting; narrow angles occurred in all of the blocks above trunks that were not separating except in the older block of Willows. In this latter lot of trees angles as wide as 45 degrees were not an unfailing protection against trunk splitting.

Very narrow angles almost invariably result in creasing, if they do not result in splitting (Table 6), but narrow angles are not a necessary

TABLE 6.—ANGLES AND SIZES OF BRANCHES IN OLD TREES IN RELATION TO TRUNK SPLITTING AND CREASING

Trunk split down—degree of angle			Trunk deeply creased—degree of angle			Trunk not split nor deeply creased—degree of angle		
Large branch	Medium branch	Small branch	Large branch	Medium branch	Small branch	Large branch	Medium branch	Small branch
Jonathan—25 years old								
15	..	..	30	45	25	35	70	45
30	..	..	15	65	45	30	10	70
15	..	..	15	15	..	..	15	..
15	..	..	25	30	..	..	50	..
15	..	..	..	10	..	..	..	..
10	..	..	..	30	..	..	..	..
15	..	..	..	..	..	..	..	..
Willow—41 years old								
45	35	..	40	30	45	72	85	85
45	30	..	50	20	..	50	80	85
30	..	..	30	..	..	60	80	..
35	..	..	45	..	..	60	55	..
40	..	..	30	..	..	40	50	..
10	..	..	..	..	..	75	85	..
15	..	..	..	..	..	..	60	..
40	..	..	..	..	..	..	90	..
25	..	..	..	..	..	..	..	..
15	..	..	..	..	..	..	..	..
Willow—35 years old								
15	20	..	30	25	..	40	70	..
15	..	..	30	40	..	..	..	..
15	..	..	40	..	..	..	..	..
5	..	..	25	..	..	..	..	..
5	..	..	15	..	..	..	..	..
..	..	..	15	..	..	..	..	..
..	..	..	45	..	..	..	..	..
..	..	..	50	..	..	..	..	..
..	..	..	30	..	..	..	..	..
..	..	..	30	..	..	..	..	..
..	..	..	10	..	..	..	..	..
Minkler—35 years old								
15	20	..	30	25	..	40	70	45
15	..	..	30	40	..	..	..	..
5	..	..	40	..	..	..	..	..
5	..	..	25	..	..	..	..	..
15	..	..	25	..	..	..	..	..
..	..	..	15	..	..	..	..	..
..	..	..	15	..	..	..	..	..
..	..	..	45	..	..	..	..	..
..	..	..	50	..	..	..	..	..
..	..	..	30	..	..	..	..	..
..	..	..	30	..	..	..	..	..
..	..	..	10	..	..	..	..	..

factor, since deep creasing occurs occasionally below wide angles (Fig. 17).

The relation between the size of branch and the occurrence of trunk splitting is also clearly indicated in Table 6. Under branches of medium size none of ten Jonathans and only two of twelve of the older Willows have separated; under larger branches the proportion in the same two blocks was seven in thirteen and ten in twenty-one. There are too few branches of medium size in the other two blocks to make similar comparisons. Trunk splitting did not occur below any of the small branches.

Table 6 also shows a progressive shifting from the smooth trunk thru the stage of deep creasing toward trunk separation as the size of branch increases. Altho deep creasing, and often splitting, has occurred under almost all of the large branches, under branches of medium size creasing without splitting has been more common than splitting, and under the smallest branches the comparatively smooth trunk has been the most common condition. In branches of any one size, the smoother trunks usually occur under branches which are taking rather wide angles.

FIG. 17.—CREASING BELOW WIDE ANGLE ON JONATHAN

Creasing occasionally occurs below large branches which leave the trunk at a wide angle.

In most of the possible comparisons irregularities and exceptions can be found. The best correlation between creasing and the factors which lead to it or tend away from it is found between wide angles and freedom from creasing or splitting, but even here extreme exceptions occur; Table 6 shows two branches of medium size and narrow angle (10 and 15 degrees) above trunks which are not even deeply creased.

INFLUENCE OF TYPES OF GROUPING ON TRUNK SEPARATION

In Table 7 the importance of angle in relation to trunk separation is again brought out, and certain additional relationships between trunk splitting and the arrangement of the framework branches relative to each other are suggested. Creasing and splitting are not separated in the table, because it is assumed, on account of the relation brought out above, which can be seen in any block of old trees, that the former is often an incipient stage of the latter.

In this table data are assembled from 28 vase-shaped trees in a well-cared-for commercial block of old Jonathans, and arranged according to the total number of branches in each tree and the number of main branches in each subdivision of each trunk. If, for example, there are three main branches, one of which leaves the trunk separately, while the other two, originating at about the same point,

constitute a unit in relation to the trunk, the table indicates in the second column two main subdivisions; the table shows that the number of main branches in one of these subdivisions is one and that it is two in the other. The subdivisions made up of more than one branch can be referred to as a group. Grouping in old trees can be recognized

TABLE 7.—COMPARISON OF NUMBER OF BRANCHES AND CONDITION OF TRUNK BELOW ANGLES IN 38-YEAR-OLD VASE-SHAPED JONATHANS

Number of main branches		Degree of angles between branches and condition of trunk below each angle[1]
Total number	Number in each main subdivision	
2	1, 1	*5*, *5*
2	1, 1	*15*, *15*
2	1, 1	*15*, *15*
2	1, 1	*17*, *20*
2	1, 1	*30*, *30*
2	1, 1	35, 35
2	1, 1	45, 45
2	1, 1	55, 55
3	1, 2	*5*, *5*
3	1, 2	20, 20
3	1, 1, 1	*5*, 25, 20
3	1, 1, 1	40, 5, *30*[2]
3	1, 1, 1	10, 20, 25
3	1, 1, 1	22, 10, 25
3	1, 1, 1	*25*, 50, 45
3	1, 1, 1	50, 50, 35
4	1, 3	*5*, *5*
4	2, 2	20, 20
4	1, 3	*25*, *25*
4	1, 3	*45*, *45*
4	1, 1, 2	*5*, 45, 45
4	1, 1, 2	55, 15, *10*
4	1, 1, 2	*18*, *15*, 35
4	1, 1, 2	40, 35, 40
4	1, 1, 1, 1	40, 50, 45, 50
5	1, 1, 3	*25*, 35, *25*
6	1, 5	*10*, *10*
6	1, 1, 4	*45*, *45*, 50

[1]Degree of angle italicized if trunk below angle is creased.
[2]A knot in the trunk below the narrowest angle may have prevented cleavage.

by looking thru the framework. The characteristics which make it possible to distinguish a group most easily and unmistakably as a single unit are creasing down the trunk below the angles of the outer members and a common line of cleavage around the group in the crotch. In the old tree the entire group, if it is sufficiently distinct, becomes separated from the remainder of the tree if the tree splits down. In the old trees described in Table 7 grouping could be recognized easily even in the absence of deep creasing.

The table supplies additional evidence of the undesirable effect upon the trunk of narrow angles. It was only among trees with two main framework branches, however, that narrow angles invariably resulted in creasing, probably because the comparative size of each main branch decreased with the increase in number.

Grouping in this block of Jonathans was infrequent among vase-shaped trees with three main branches, but it occurred in eleven of the twelve vase-shaped trees having four or more branches. Where grouping occurred, two main subdivisions and three main subdivisions were formed an approximately equal number of times, thus tending to reduce the total number of main divisions of the framework in the same way that the total number of branches is reduced as the tree grows older. A number of trees in which the total number of branches exceeded three formed single groups of several branches each, so that the framework was divided between one or two large branches and a group of several smaller branches. This arrangement was common in heads with four main branches or more, and increased with the number of branches. In one tree with six main branches one lower main branch constituted approximately half of the top, while the remainder originated in five smaller branches grouped together. The angle between the single branch and the group was only 10 degrees and the trunk was beginning to separate. From the standpoint of trunk splitting the tree might as well have been trained to two main branches. In the other framework with six branches, one group of four had been formed and the trunk was separating in spite of an angle of 45 degrees.

When the branches developed into two main subdivisions, the angles were narrower than if three subdivisions were formed. The angles were very wide in the single four-branched tree in which there was no grouping. This again illustrates the same relation in the mature tree between close angle, a vertical direction, and large size that exists in the young tree. (See Fig. 3, page 536)

None of the thirteen central-leader trees in this same block were creasing or separating, with one exception. In this single exception, separation was beginning below a large branch which took an upright direction and left the trunk at an angle of 5 degrees. In the other central-leader trees the undesirable characteristic of narrow angle (which the above data show is the most important single factor in separation) and the correlated characteristic of large-sized individual branches or groups had been avoided. All of the angles were wide, usually in the neighborhood of 90 degrees. It is significant, from the standpoint of training, that this result had been obtained in a commercial orchard with no particular foresight or effort on the part of the grower.

Varietal Differences Influencing Splitting

Grouping in the Delicious and the very strong tendency toward trunk separation in that variety are shown in Table 8. The trees, which were only twelve years old, had been uniformly headed back when

they were whips to start the framework. The heads varied from 15 to 24 inches in distance from the ground. They had all developed into the vase-shaped type. In many trees trunk separation had reached the stage shown in Fig. 11, page 559.

As shown in Table 8, grouping had occurred in almost all heads in which there were more than three main branches, and it is clear that there was a very strong tendency in this variety toward the limitation of the number of main subdivisions, or groups, to two or three.

TABLE 8.—GROUPING AND TRUNK SPLITTING IN ANGLES IN DELICIOUS TREES TWELVE YEARS AFTER CONVENTIONAL HEADING-BACK CUT

Total number of branches	Number of subdivisions	Number of planes of cleavage	Degree of angles above planes of cleavage
2	2	1	10
2	2	1	10
3	2	1	10
3	3	1	40
3	3	1	15
3	3	2	20, 15
4	2	1	5
4	3	1	35
4	3	1	25
4	3	2	20, 15
4	3	3	40, 35, 45
4	3	3	10, 20, 15
4	3	1	5
4	4	0	......
4	4	0	......
5	2	1	5
5	3	3	15, 15, 15
5	3	1	25
5	3	2	35, 10
6	2	1	45
6	3	2	5, 15
6	4	2	40, 20

Separation had occurred in at least one plane in the trunks of all but two of the twenty-two individuals, and in some cases separation had taken place along three planes.

It will be noted that, altho angles above planes of cleavage were usually acute, grouping and trunk separation were taking place under wider angles also, and that these angles were sometimes as wide as 45 degrees. In trees of this variety, pruned in this way, fairly wide angles are therefore not a sufficient protection against either grouping or trunk separation. Because of the lack of correlation between trunk separation and branch angle, it is clear that other factors play a part in the splitting of trunks of this variety, as in Jonathan, Willow, and Minkler.

Just why trees of the variety Delicious split down easily is not clear, but it probably depends upon several varietal peculiarities. The

difference is not to be attributed to more pronounced ridging, since other varieties, of which the Jonathan is the best commercial example, ridge more deeply and split down less frequently. Still other varieties, of which the Willow is the best example, ridge more deeply and, altho they usually split down, do so as a rule only when considerably older. Rapidly growing trees of most varieties appear to have the same tendency as the Delicious toward grouping, but do not necessarily split down, so that the tendency to split cannot be explained on this

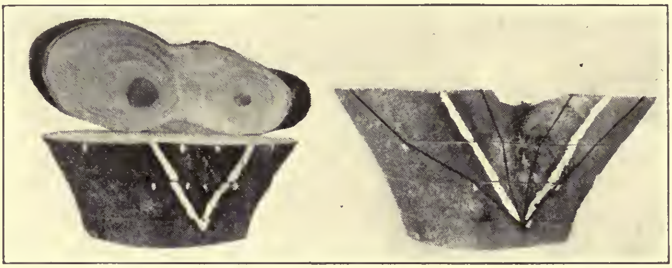

FIG. 18.—FORMATION OF STRONG CROTCH TISSUE BETWEEN WIDE-ANGLED BRANCHES

The white lines show the amount of growth on the inner and outer side of each branch as determined by consecutive cross-sections. The inner black lines on the right include the crotch tissue.

basis. Moreover, the production of narrow-angled crotches is not an exclusive characteristic of this variety; it is in fact a characteristic of rapidly growing trees in general, altho there is doubtless considerable varietal variation in the relationship between the direction taken by a branch and the rate of its growth.

Among the possible varietal peculiarities which might contribute toward resistance to trunk separation are a resistance of the wood to longitudinal splitting, a greater tendency toward bridging across narrow angles, and stronger crotch wood. The extent to which each of these or other factors may enter is uncertain. Irregularities in the course of the fibers of forest trees, according to Roth,[119] whether spiral growth, cross grain, or in the form of knots, all aid in resisting cleavage, while moisture, by softening the wood and decreasing lateral adhesion, causes the wood to split more easily when moist than when dry. According to Forsaith,[57] wood is subject to a considerable variation in structure, weight, and moisture content, all of which, by exerting a pronounced influence upon strength, make it impossible to obtain a specific strength value for any particular species of forest tree. The proportion of heartwood in trunks does not, according to Cline and Heim[32] and Forsaith,[57] bear any relation to breaking strength.

One can assume that varieties of apple trees and individual trees and crotches differ in some, at least, of the characteristics that are said to be significant in forest trees, or in other characteristics of a similar nature. Without evidence to the contrary, it would be assumed, for example, that varietal differences and seasonal variations in water content are important. On this basis, the tree should split most easily in the spring, when the water content is highest, as Farmer[56] has shown, and some varieties might easily be less resistant than others when loaded with fruit because of a slower decrease in the water-content of the wood in the fall. Grossenbacher[65] suggests the hypothesis that an enzymatic softening of mature wood occurs during the period of most active growth, because stems and branches of trees are most easily bent during the spring period of active growth.

FIG. 19.—WEAK CROTCH CAUSED BY BARK INCLUSION

Very little wood has been built up between the branches of this crotch, owing to the narrow angle. The small amount that has been formed is separated by bark, resulting in a weak crotch. Compare with Fig. 18.

MacDaniels[96] has reported, incidental to his study of the strength and structure of apple-tree crotches, that varietal differences among crotches are less important than the individual crotch differences. Altho he states that there are varietal differences in the strength of crotch tissues, the actual arrangement of the cells seems to him to depend upon the crotch angle and the relative size of the two arms more than upon the variety. He concludes that, other factors being equal, the strength of the crotch depends upon the width of the angle, and upon a difference in size between the two arms.

Bridging within the crotch between two branches which have formed a rather wide-angled fork is shown in Fig. 18. This crotch differs essentially from the crotch shown in Fig. 19, in which bark, caught between the growing arms, has prevented the formation of continuous crotch tissue.

Tests to Determine Breaking Force of Crotches

MacDaniels[96] claims that crotches between branches of unequal

size are strong because the larger branch grows around the base of the smaller one, so that the wood of the side branch becomes imbedded in the wood of the main axis. Assuming that MacDaniels' data[96] (Table 1, page 7 of reference) really show that the strength of the crotch increases with the angle, the same data show that a difference in the size of the two arms of a crotch is not a factor in its strength, when rearranged to bring out this relationship. Such a rearrangement is made in Table 9. Since in this comparison it is necessary to keep the angle as nearly constant as possible, only the sixteen

TABLE 9.—BREAKING STRENGTH OF CROTCHES WITH ARMS OF EQUAL AND UNEQUAL SIZE
(From data published by MacDaniels)

Branch number	Diameter main branch divided by diameter side branch	Degree of angle	Strength per inch in pounds	Diameter in inches	
				Main branch	Side branch
11	1.00	52	102	1.12	1.12
22	1.00	43	55	1.06	1.06
24	1.00	44	55	1.00	1.00
17	1.06	39	70	1.00	.94
Average	1.01	45	71	1.05	1.03
3	1.12	35	48	1.12	1.00
20	1.12	41	75	1.12	1.00
4	1.12	45	60	1.12	1.00
5	1.12	45	72	1.12	1.00
Average	1.12	42	64	1.12	1.00
2	1.22	34	80	1.37	1.12
21	1.37	39	60	1.37	1.00
12	1.26	51	65	1.18	.94
Average	1.28	41	68	1.31	1.02
1	1.44	39	45	1.25	.87
23	1.50	39	40	1.31	.87
26	1.50	49	135	1.87	1.25
19	1.56	37	110	1.75	1.12
18	1.65	43	64	1.75	1.06
Average	1.53	41	79	1.59	1.03

crotches, of the twenty-four in MacDaniels' table, with an intermediate angle between 39 and 50 degrees are included. No change, other than rearrangement of the order in which the branches appear, has been made in MacDaniels' data.

MacDaniels determined the force necessary to break the branch by hanging weights on the side arm, after strapping the main limb to a post. The weights were applied "at a point one foot perpendicular distance from the main limb so that the leverage of the weight was the same in each case," and "in order to make the results comparable, the breaking weights were computed by simple arithmetical proportion to correspond to side-arm diameters of 1 inch in each case. Thus, if the side-arm diameter was 1¼ inches and the breaking strength 155

pounds, by using the proportion $1\frac{1}{4} : 155 = 1 : X$ the value of X is 124, which would be an indication of the breaking strength if the side arm was 1 inch in diameter."

The data in Table 9 do not indicate that forks in which the arms are of unequal size break less easily than forks in which the two branches are of about the same size. The average for the resistance of the crotches with the widest angles should probably be reduced by excluding Branch 26, which is larger than the others, because the largest branches required the application of a force out of proportion to their diameters. On the average, the weight per inch required to break the ten branches with a diameter of an inch or less, which had an average diameter of .96 inch, was 59 pounds per inch, while the corresponding weight per inch required to break the branches with a diameter above one inch, averaging 1.53 inches, was 91 pounds per inch. If Branch 26 were excluded, the averages would be still closer together. If the data are recalculated on the assumption that the side arm varies in strength with the cube of its diameter, breaking like a horizontal round beam, instead of with the first power, which MacDaniels uses, there is still less correlation between inequality in size of the side arm and the resistance of the crotch. The larger branches then require too much, rather than too little, force to break them.

Since it is the force acting at a right angle to each arm of a fork which splits it, the fork with vertical arms should, in fact, prove to be the stronger, other things being equal, when a weight is applied to the smaller arm as it is in nature when the tree bears a crop. If the branch is compared to a column, it is obvious that the more vertical it is, the greater is the weight which it will support without, in the case of the column, tipping over, and, in the case of the branch, without breaking off at the base.

A few experiments with a similar object were carried out at Urbana in March, 1930. Jonathan crotches of various angles and with arms of equal and unequal size were used. Altho only sixteen forks were broken, the work will be described because it indicates the nature of the problem. In this work two 14-year-old Jonathan trees were cut down, and forks were selected and cut out. These trees had not yet borne a heavy crop but could be expected to do so at any time. The forks were between the larger branches, and some of them would presumably break down in case of a very heavy crop. No forks were used in which the diameter of the smaller branch was less than 1.31 inches. The average size of the smaller arms was 2.55 inches; in the largest fork this diameter was 4.25 inches. The average size of the

larger arm was 3.52 inches; the extremes were 2.06 and 5.00 inches. All tests were carried out on the day when the trees were cut down to avoid the increased resistance which would result from drying out.

To make a test, all branches were removed from the arms of each fork and one arm was chained to the floor. The force was applied to the other fork with a cable and windlass. The point where the cable was attached to the side arm varied according to the size of the branch. On small branches it was necessary to make the attachment close to the crotch to decrease bending. The side arm of the smallest fork was 1.31 inches in diameter, and in this case the cable was attached 3½ inches from the crotch, for the reason that side branches of this size and smaller could be bent down until the end paralleled the parent branch without breaking the crotch if the force were applied at any great distance (15 or 18 inches). On larger and therefore more rigid side arms the cable was attached at points 8 to 18 inches from the crotch.

FIG. 20.—STRONG CROTCH BETWEEN EQUAL BRANCHES

As much force was required to start separation in the above crotch as between arms of unequal size.

The windlass was a part of a movable crane, the position of which was so adjusted in relation to the fork that breakage would occur, as closely as could be foretold, when the cable and the fork to which it was attached were at right angles. One purpose in observing this precaution was to avoid the necessity of recalculating the result according to the direction thru which the force was acting at this point. It was also thought that applying the force in some other direction than at right angles might produce other results. This rather minor point illustrates the difficulties that were encountered in the experiment.

A dynamometer was used to record the pull. It was attached directly to the branch on one side and to the end of the cable on the other, so that the frictional resistance of the pulleys did not affect the accuracy of the result. Thruout each test the dynamometer was observed from the time the force was first applied until the test was completed. The dynamometer reading was recorded at the instant when the crotch started to break.

In the eight tests carried out last, which were intended to be preliminary to further work, records were made of the angle of the fork

before the force was applied, of the diameter and age of each arm, of the radius of each branch toward the inside and outside, of the diameter of the heartwood and sapwood, and of the number of rings of each type of wood. These measurements were made at a point just outside the "collar." The depth of the crotch tissue between the two arms, and the distances between the point of attachment of the cable and the crotch, and between the former point and the "point of insertion" of the side arm were also recorded. The latter was the point where the oldest wood in the side arm joined the parent branch. In addition, a record was made of the horizontal distance between the point of insertion and the outer edge of the side arm. The way in which each branch broke was observed and described.

FIG. 21.—PRUNING WOUNDS WEAKEN BRANCHES

In the test, the above branch broke off just outside the collar where a large lateral had been removed two years before.

Breakage occurred as MacDaniels described it, that is, branches of equal size which had taken an equally upright direction split apart like the branches in Fig. 20, the split continuing down the parent stem. In case there was a difference in size, so that the branch which had been chained down could be spoken of as a main branch, while the branch to which the force was applied was a side arm, the lower end of the smaller branch was usually pried out of the larger branch at the point of insertion as one might pry a stone out of the ground with a crowbar. The only exception was one fork in which breakage occurred across the arm at the outer edge of the shoulder. At this point a large secondary branch had been removed two years previously (Fig. 21), and the wood seemed to have been weakened by rot. In case the base of the smaller branch was pried out, the wood of the parent branch or stem below the side arm was not split down except by continued pulling after the smaller branch had been brought down considerably past a direction corresponding to the horizontal. When the windlass was wound up further, after the arm had taken this direction, a longitudinal strip of wood below the side arm could be pulled out.

When the results of the last eight tests were examined, it was found that little evidence of correlation could be obtained between the force required to split the crotches and the angles, the relative size of the

two arms, or any of the other characteristics of the forks which had been recorded. The closest correlation that was found lay between the force calculated at a uniform distance from the crotch and the square of the diameter of the smaller arm. The former divided by the latter gave a fairly constant figure. Altho this correlation is probably accidental, on account of the small number of samples studied, and is entirely empirical at best, the data upon which such a relationship might be suspected are given in Table 10. This table also shows the lack of correlation between breaking force and some of the other factors which one might suppose would inevitably play a part.

The dynamometer readings in the table are not converted to pounds. The force at 24 inches was calculated by multiplying the dynamometer reading by a fraction the numerator of which was the distance in inches between the point of application of the force and the crotch and the denominator of which was 24. The forks from which the data in the table were obtained were from one tree, with the exception of the first. Two forks upon which detailed records had been made, but in which the wood proved unsound, were not used.

The lack of relationship between breaking strength and some such factor as angle or a difference in size between the arms made it desirable to try to determine, before further testing, the way in which the force had acted in producing breakage. The lack of correlation might have been due to a fault in the method of breaking the crotch, so that the force actually reaching the crotch was not proportional to the force recorded on the dynamometer, or to a misinterpretation of the dynamometer reading because of factors not being considered. The principal difficulty was to determine, or even to estimate, the direction and distance thru which the force that had broken the crotches had acted. When branches of unequal size were used, some part of the branch to which the force was applied necessarily acted as the longer arm of a lever, some point toward the outside of the crotch acted as a fulcrum (Fig. 18), while some part of the lower end of the branch acted as the shorter arm. If the fulcrum could have been located exactly, which was an obvious impossibility, the length of the two arms might have been determined, but other uncertainties would then have entered, such as differences in the lateral distribution of the force due to differences in the shape and structure of the crotch tissue. A similar relationship of forces as parts of levers when branches were equal in size and upright in direction, as in Fig. 20, tho not at first so apparent, evidently held true also.

In view of the fact that the unknown factors entering could not be determined individually, a formula to express the relationship be-

TABLE 10.—RELATIVE FORCE REQUIRED TO SPLIT CROTCHES OF 14-YEAR-OLD JONATHANS

Larger arm			Smaller arm			Larger diameter divided by smaller	Degree of angle	Depth of crotch tissue	Percent of heart-wood	Force at 24 inches from crotch divided by square of diameter of smaller arm
Inside radius	Outside radius	Diameter	Inside radius	Outside radius	Diameter					
inches	*inches*	*inches*	*inches*	*inches*	*inches*			*inches*		
1.88	1.69	3.57	.75	1.19	1.94	1.84	70	3.75	39	37.9
1.88	1.69	3.57	.69	1.06	1.75	2.03	47	3.75	50	39.4
1.44	1.56	3.00	.75	1.31	2.06	1.46	34	2.88	34	34.6
1.25	1.75	3.00	.63	1.25	1.88	1.60	56	3.12	33	27.4
1.63	1.50	3.13	.50	.81	1.31	2.38	68	3.63	67	32.2
1.75	2.19	3.94	1.19	2.38	3.57	1.10	25	5.50	68	35.4[1]

[1]This branch broke cleanly into two halves (see Fig. 20).

tween the characteristics of the fork and the force necessary for breakage would necessarily be empirical, and could be found only, if at all, by carrying out a large number of tests. For reasons stated above, a constant formula could probably not be obtained, and such a series of tests would hardly be worth while, because the actual and relative strength of a crotch would probably vary with the variety, and even with the individual, as well as with the time of year and the weather. It is, moreover, doubtful if calculations of this sort would be of much value unless the arm itself were the part to break. As long as breakage occurs within the crotch, which is usually the case, neither the absolute nor the relative size of the side arm could be of direct importance, altho it might afford an indication of the amount and condition of the supporting tissues and the lines thru which the forces would act.

Further results that the writers could have obtained by the method in use would also have been difficult to interpret in terms of actual field breakage, because the leverage produced by the weight of the fruit and the weight of the branch depends upon the center of gravity and the directions of both arms in the vertical plane. The forces applied in the laboratory were not the counterpart of those that would be exerted naturally. The tests were therefore discontinued.

A further observation in regard to the way in which the crotches broke can, however, be reported. The greatest force, as registered by the dynamometer, was always required just before the crotch tissue started to separate, as indicated by the development of a crack within the crotch tissue. As this crack deepened, the force as registered rapidly decreased to about one-third or less, and it did not increase if the windlass was wound up sufficiently to split the wood of the parent branch. This indicates that the crotch tissue is the source of most of the resistance.

When the arms were equal in size and upright, as in the last example in Table 10, the drop registered on the dynamometer after separation of the crotch was more rapid, and the force fell to a lower point than when the point of insertion of the side arm was pried up. In the latter case it required continued force to tear the longitudinal strip of wood out, probably because it was irregularly shaped with a greater extent of surface less regularly arranged than when a clean flat break occurred. This is a further difference between the crotches of the two types.

Strength of Crotch Dependent on Soundness of Crotch Tissue

The results of the above tests, as far as they go, indicate that the strength of crotches is to be attributed largely to the soundness of

the crotch tissue, particularly to its freedom from bark inclusion, and that increase in angle beyond the point necessary to prevent the inclusion of bark may not increase the strength of the crotch. Several forks were found in which bark had been caught deep in the crotch, but not in the newer crotch tissue formed toward the outside. This change should be a source of increasing strength. Another factor to be considered is the elasticity of the smaller branches, which are likely to bend without breaking.

Growth Against Pressure As a Factor in Trunk Splitting

That crowded branches force themselves apart by their own growth has been assumed by Alderman and Auchter[3] and Fagan and Anthony.[55] The arms of close forks, because of the flattened faces where the surfaces grow into contact, appear to be pushing away from each other, and perhaps splitting the trunk (Fig. 22). Such an assumption would seem to be reasonable because of the force which plants exert in lifting pavements or curbings. Stone[130] records an instance, under his observation, in which the corner of a house was lifted by the growth of roots from a near-by tree, and another in which a concrete pavement was repeatedly broken by the persistent development of fronds from the rhizome of an adjacent ostrich fern.

FIG. 22.—PRESSURE BETWEEN CLOSE FORKS

Two framework branches which have grown together in the above tree seem to be pushing against each other.

It has been shown that expanding stems and branches are capable of overcoming considerable resistance before growth stops. Krabbe[88] calculated, from his experiments with forest trees, that in hardwood trees this force of resistance was equivalent to at least 15 atmospheres. Von Schrenk[139] concluded that hardwood trees were able to overcome even greater resistance, because as the trees grew they were able to break most of the ligatures spun by bagworms around the twigs, which breakage he found required a tension equivalent to a pressure of 40 atmospheres. He concluded that

the wood underneath was exerting this much force. Altho the pressure necessary to stop growth was not determined or estimated by Krabbe or von Schrenk, it appears to be very considerable.

Whether or not branches can split the trunk below by pushing against each other as they grow depends, however, not only upon the resistance which the growing wood is capable of overcoming before growth ceases, but upon the space, perpendicular to the plane of cleavage, thru which the force acts. This, in turn, is dependent on the thickness of the layer of wood formed under pressure. If there were no cessation or retardation of growth as the pressure increased, trunk splitting would be inevitable, and it would be probable if growth were decreased only slightly.

It has been shown repeatedly, however, (Krabbe,[88] Küster,[90] Newcombe,[110] von Schrenk,[139] Pfeffer,[115] Hottes[75]) that the elements of the xylem developing under pressure do not attain normal size. Krabbe[88] found that a pressure corresponding to 5 to 7 atmospheres was sufficient to reduce growth in hardwood trees, and von Schrenk,[139] in summing up the changes which occur in the region of wood under ligatures produced by bagworms, states that with an increase in pressure smaller and smaller cells are formed. As the pressure increased the cambium continued to form new cells up to a certain point, but at a decreased rate. The flattening of stems (*Hedera* and *Ficus*) is due, according to Küster,[90] to the retardation of growth at points coming into contact; as soon as the pressure becomes too great the growth of cambium and meristem ceases.

One would, therefore, anticipate either the formation of thin rings of wood or the entire cessation of radial growth where the faces of crotches touch each other. The writers attempted to determine the decrease in radial growth along the faces of arms of forks in contact, but found that the interpretation of the result was complicated by the impossibility of excluding other factors limiting growth.

In crotches which were examined the smaller arm almost invariably made less radial growth on its inner than on its outer side, even when it did not make contact with the larger arm. The larger arm was variable, sometimes making more growth toward the inside and sometimes toward the outside (Table 10). It is likely, therefore, that if growth against pressure is a factor in trunk splitting, the larger branch exerts the more effective leverage, and that if both branches are upright more pressure is exerted than if one branch is smaller. The direction in which the smaller branch grows, also, should be more easily changed, and it may easily be sufficiently flexible to be bent away without damage to the trunk.

Varietal differences in the survival of wood growing under pressure are to be anticipated, but the differences may not be great enough to account for varietal differences in trunk separation. It is even possible that growth against pressure is not a factor in any variety.

SUMMARY OF STUDY OF RESULTS OF CONVENTIONAL HEADING PRACTICES AND OF DEVELOPMENTAL TENDENCIES WITHIN THE FRAMEWORK

1. Heading back the one-year whip has produced vase-shaped trees, and only occasionally central-leader trees. Modified central-leader trees have not been produced.

2. The central-leader tree often loses its lower branches. Other branches are lost also, and the tendency is toward wider and wider spacing. The tree does not reach a permanent state of equilibrium in this respect.

3. The mature vase-shaped tree usually has from two to four main branches.

4. Because of the gradual elimination of branches in both types of tree, long bare spaces are produced along the main branches. No permanent state of equilibrium is reached.

5. There is little suggestion of varietal difference in response to the conventional heading-back cut; vase-shaped trees are produced regardless of variety.

6. The vase-shaped tree originating in this way requires less severe wounding later in its life than the central-leader tree.

7. Only a very limited number of main branches can be maintained permanently in either type.

8. Trunk splitting is a varietal characteristic, which is not necessarily correlated with ridging and creasing (also varietal characteristics), tho ridging and creasing constitute a preliminary stage of trunk splitting in certain varieties.

9. Trunk splitting is favored by narrow crotch angles and a small number of large framework branches or the grouping of main branches.

10. Central-leader trees seldom break down because of trunk splitting. In such trees branch angles are wide, main branches are comparatively small until the tree reaches an advanced stage, and grouping does not occur.

11. Crotch strength seems to be due more to soundness of the crotch wood than to the crotch angle and only indirectly to a difference in size between the arms.

12. Differences in growth habits, and possibly a greater tendency toward growth against pressure in particular, may be one cause for difference between varieties in their tendency to break down.

EXPERIMENTAL STUDY OF METHODS OF TRAINING YOUNG TREES

The object of the work to be described, as already indicated, has been to develop a method of training that would produce a longer-lived tree than the present system of training produces by providing it with a more permanent framework. In this new method crowded and grouped framework branches, bad angles, and poor balance within the main framework, which are the result of the method of training now employed, were to be avoided. A rather small number of branches, spaced at fairly wide intervals, were to leave the trunk at angles wide enough to prevent the inclusion of bark, but were to assume an upright direction. Uniformity in size was desirable. A retardation in the growth rate of the young tree and a delay in production, which result from following any method of training, were to be expected; if better trees were produced, a considerable delay in production would be permissible. Nevertheless the growth rate was to be retarded as little as possible. The best method of training would produce a permanent framework in the first year, without the necessity for heavy pruning either in its production or in its maintenance.

Twelve commercial varieties and a total of 508 young trees, most of them one year old and all of them planted for this purpose, have been used in the experiment. Three plantings were made, the first in 1924, the second in 1925, and the third in 1928. In the later plantings the earlier experiments were repeated, but the plan was modified to take advantage of the results obtained and the possibilities and problems that arose as the work progressed. The methods used and the results obtained with each planting are described and summarized separately; later the conclusions for the whole are drawn.

At this point it is well to recognize the fact that no experiment of this kind can be fully described. For one reason, it is impossible to describe the material entering into the experiment. To illustrate, no two whips which appear similar grow alike when subjected to heading back that appears to be equally severe; therefore either the material or the treatment, or both, must differ. The factors responsible for the difference, and their relative importance, are unknown. It is also evident that the relative weight of each factor must shift from year to year, from one variety to another, and with the site.

FIRST PLANTING

The first planting in the experiment to develop a new method of training consisted of 20 two-year Winesaps, 20 one-year Delicious, 20 two-year double-worked Grimes, 24 two-year Jonathans, and 24 one-year Golden Delicious. Half of the trees were used to try out disbudding in forming framework branches. The rest were used to test the possibility of starting some of the framework branches by pinching back the central leader in the summer, while it was still growing. All of the trees were of good size and in good condition when planted.

Disbudding

Methods.—While still dormant the one-year trees were headed back to a point 28 to 30 inches above the ground. Considering the size and condition of the trees this was a fairly severe cut, altho not extreme. The two-year trees were pruned at the same time by removing all of the last year's growth except one strong vertical branch. This branch was to be used as a central leader, upon which the lower main framework branches were to be developed. All of the trees in this part of the experiment were "disbudded" on June 19. By that time they had "feathered out," and shoots less than ¾ inch long had already formed terminal buds. The treatment was really more "deshooting" than disbudding.

In disbudding one-year trees, three shoots were left, one at a height of from 10 to 18 inches above the ground, another just below the point where the whip had been cut back, and another at an intermediate point. In disbudding the one-year central leaders of the two-year trees, a shoot was left on each third part of the leader, and the central leader was cut back to the highest shoot left. The average intervals between the highest and lowest shoots selected were 14.7 inches on the Winesap trees, 13 inches on the Delicious, 13.5 inches on the Grimes, 11.5 inches on the Jonathan, and 9.9 inches on the Golden Delicious.

Observations were made about one week before the trees were disbudded to determine the relation of height to feathering out. At the time disbudding was done (June 19) the shoots left were measured. The same shoots were measured again in November.

Relation of Height to Feathering Out.—The proportion of buds that had burst on June 10 to those that had not was used to determine the relation of height to feathering out. It was assumed that this relation would, to some extent at least, determine the possibility of disbudding, and that the information could be used in studying its effect. It was found that the Grimes had feathered out uniformly and almost

completely from top to bottom, while fewer buds had burst on the lowest quarter of the last year's growth of the other four varieties than on the part above. The upper three-quarters had feathered out about equally on the Jonathan, Delicious, and Winesap, but the upper half of the Golden Delicious whips had feathered out more fully than the third quarter. It was found, however, that shoots were available at all heights, even below the point where they would be needed.

Relationship of Initial to Final Shoot Length.—Shoots selected for framework branches at the various heights had made about the same average growth at the time the trees were disbudded (on June 19),

TABLE 11.—AVERAGE LENGTH OF SHOOTS MEASURED JUST AFTER DISBUDDING CENTRAL LEADER AND AFTER GROWTH HAD STOPPED, 1924
(All measurements in inches)

Variety	Lowest shoot		Intermediate shoot		Highest shoot	
	June 10-11	Nov. 10	June 10-11	Nov. 10	June 10-11	Nov. 10
Delicious	2.69	21.57	1.38	18.25	1.58	19.22
Golden Delicious	4.05	23.40	4.50	21.30	3.75	24.50
Winesap	4.40	21.75	4.92	21.22	4.35	24.15
Grimes	4.40	23.87	5.70	23.20	4.80	24.70
Jonathan	3.50	15.30	3.90	16.35	7.40	15.11

TABLE 12.—LENGTH OF WINESAP SHOOTS SELECTED FOR FRAMEWORK BRANCHES MEASURED JUST AFTER DISBUDDING AND AFTER GROWTH HAD STOPPED, 1924
(All measurements in inches)

Tree No.	Lowest shoot		Intermediate shoot		Highest shoot	
	June 19	Nov. 10	June 19	Nov. 10	June 19	Nov. 10
1	1	11.5	3	10.75	.5 T[1]	20
2	3	25.5	2.5	24.75	2.75	22.5
3	1	25	.75	18	.25T	11.25
4	1.75	25	.5 T	16.5	.25T	19
5	.25T	15	.25T	13.5	.5 T	16.25
6	1.5	18.5	.75	16.75	3	19.5
7	1.1	20	.5 T	18	.5 T	20
8	1.75	25.5	3	24	3.5	25
9	7	26.5	.5 T	21.5	1.5	20.5
10	3.5	22.5	2	18.75	3	18

[1]Formation of terminal bud before June 19 is indicated by T.

which was about two months after they had been given the dormant heading back. This relation to height still held when the same shoots were measured in November, after growth had stopped. The average lengths at these two stages are given in Table 11.

If the trees had been left to develop without interference after heading back, the highest shoots would have grown, as a rule, to a much greater length than those lower down, so that it can be concluded that the great advantage of proximity to a rather severe heading-back

cut, and the corresponding disadvantage of distance, had been overcome by disbudding. This was in spite of a considerable space between the laterals. A typical result is shown in Fig. 23.

The result of disbudding is brought out more clearly by comparing the length of individual shoots immediately after disbudding with their final length (Table 12). Data from the Winesap are given because of its greater variation in shoot length at disbudding. Any correlations between initial and final length can therefore be seen more easily.

FIG. 23.—LATERAL DEVELOPMENT AFTER DISBUDDING

The whip of this Delicious was disbudded to three buds. The branches from the lowest buds have grown as much as the branch from the highest bud.

The data show that in most of the disbudded trees there may have been a certain degree of correlation between initial and final length, but that most of the advantage of greater initial length had been lost. The same was true of the advantage of a higher position on the stem; the final length of the highest shoot of only one tree (No. 1) greatly exceeded its earlier comparative length. Shoots which had formed terminal buds before disbudding made less growth than those which had not, but they were also the shortest shoots at the earlier period. From the data it is not certain that the formation of a terminal bud had, in itself, decreased the subsequent growth of the shoot.

Corresponding data for the Grimes are given in Table 13. The same indefinite relation can be seen between initial and final shoot length, except that there was a little more of a tendency for the highest shoot to grow out of proportion to its earlier length (see Nos. 5 and 8).

Angle and Direction of Branches Produced.—The angles of the lower two framework branches at the trunk were, as Fig. 23 shows, fairly wide, and the branches assumed a desirable upright direction. The highest branch continued the central leader.

Effect Upon Trunk Growth of Disbudding Whip to Three Single Buds.—The dwarfing effect of disbudding, when it is carried so far

that only one bud is left at each height where a branch is wanted, is shown in Table 14. The trees were pruned alike except for disbudding.

Effect of Disbudding Central Leader in Second Year.—Since the experiment was designed primarily to study the effect of disbudding, the highest new branch which could be used as a central leader, because of the vertical direction and central position that it had taken, was disbudded to three buds before active growth started in the second season. The purpose was to determine the possibility of starting higher framework branches in this way. Since there were two other branches about as large on each tree, the experiment also afforded an opportunity to study the dwarfing effect of disbudding. The two lower branches were, therefore, left without pruning. The result can be seen in Fig. 24. The effect, in short, was to dwarf the highest lateral so severely that it could no longer be used for a central leader.

TABLE 13.—LENGTH OF GRIMES SHOOTS SELECTED FOR FRAMEWORK BRANCHES MEASURED JUST AFTER DISBUDDING AND AFTER GROWTH HAD STOPPED, 1924
(All measurements in inches)

Tree No.	Lowest shoot		Intermediate shoot		Highest shoot	
	June 19	Nov. 10	June 19	Nov. 10	June 19	Nov. 10
1	3	26.5	6	22	8.5	33
2	1	20	5.5	22.5	4.5	26
3	6.5	23.5	6	24	6.3	25.5
4	2	16.5	5.8	17.8	4	20
5	4.5	11	3.5	8.8	.5T[1]	18.5
6	8	26	8.5	30.5	6	24
7	7	29	5	22.8	3.5	21.8
8	4.5	26	4.5	25	.5T	25
9	4.5	20.5	4.5	23	6.5	28
10	3	18.5	.3T	16	3.3	20

[1]Formation of terminal bud before June 19 is indicated by T.

TABLE 14.—EFFECT OF DISBUDDING TO THREE SINGLE BUDS ON GROWTH OF TREE THE FIRST SEASON AFTER PLANTING, 1924

Variety	Average increase in trunk area	
	Headed back and disbudded	Headed back without disbudding
	perct.	*perct.*
Winesap	22.7	200.6
Delicious	58.8	261.2
Grimes	52.6	223.2
Jonathan	63.7	223.8
Golden Delicious	99.4	422.8

It is possible, also, that the result of disbudding this lateral was reflected in a greater growth of the two lower laterals than would have occurred otherwise. The results indicate that the highest lateral could be disbudded only if the lower laterals were similarly treated or very

severely headed back at the same time. Neither treatment appeared to be at all desirable.

Conclusions From First Disbudding Experiment.—It was concluded from this experiment that in disbudding early in the growing season any live bud or young shoot could be chosen as a potential framework branch. Altho its original relative size might be reflected to some extent in the final relative length of the resulting shoot, the difference would be largely overcome. This growth relationship may be expected to hold true only if disbudding is done early. If disbudding is done late in the summer, shoots which have formed terminal buds much earlier may fail to resume growth if they have become more fully dormant. No direct experiments were carried out to study this point.

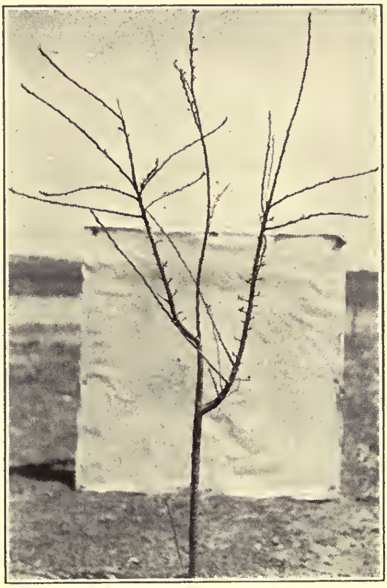

FIG. 24.—CENTRAL LEADER DWARFED BY DISBUDDING

The whip of this two-year-old Winesap was disbudded to three single buds at planting. The central leader was disbudded to three single buds at the beginning of the second year; the two framework branches were not disbudded and were at that time slightly smaller than the central leader.

Disbudding appeared to be a promising method of training, since it could be used to start framework branches at the heights and in the directions desired. The experiment showed that these laterals would be likely to be quite uniform, and that they would probably leave the whip at fairly wide angles and take an unright direction.

The experiment brought out, very strongly, the dwarfing effect of disbudding to a very limited number of buds. This held true both for whips in the first year and for single branches in the second year.

It seemed that the method used in 1924 could be modified to advantage. From the vigorous growth of the three laterals following disbudding, a greater length of the one-year whip could be utilized for the development of a greater number of laterals. For this purpose and to prevent the loss of the highest framework branch as such, which occur-

red when this branch assumed the upright direction to replace the central leader, it was thought that a desirable modification would be to leave the terminal bud of the one-year whip to continue the central leader, that is, not to prune the whip at all, or at most to head it back very lightly. It also seemed that a better set of branches might be secured if a selection were provided by saving three or four buds at each place. This would obviate the danger of the accidental loss of an important branch during the first year. The retardation in trunk growth caused by disbudding was an additional reason for leaving a greater number of buds. The trees would be likely to come into bearing slowly and, because of the slenderness of their trunks, would be especially subject to permanent bending by the wind. The next experiment in disbudding was designed to test this possibility.

Summer-Tipping

Methods First Year.—The trees planted in 1924 were treated during the first year as follows: One-year trees (10 Delicious and 12 Golden Delicious) were headed back to 28 inches. The 1932 laterals of the two-year trees (10 Winesap, 10 Grimes, and 12 Jonathan) were thinned out to a central leader and one lateral leaving the trunk at a wide angle. More laterals were left if they were available with from 4 to 6 inches of vertical separation and suitable direction. The central leader was headed back to a length of from 12 to 15 inches. On July 11 a part of the trees were "summer-tipped" by pinching back the new terminal shoot which was continuing the central leader. At that time none of these shoots had formed their terminal buds and, judging by the subsequent growth made by untipped shoots of other trees, they were growing rapidly. The amount cut off was about 1 inch regardless of the length of the shoot. Six Grimes, six Jonathan, and six Winesap trees were given this "summer-tipping" treatment, the other trees of the same variety serving as checks.

In the following dormant season measurements were made of the length of the 1924 central leader above and below the point where it had been tipped, and of the laterals (secondaries) forced out back of the cut. At the same time the length of the untipped central leaders of the check trees was determined. The diameter of each central leader was taken at a point 2 inches from its base.

Effect of Summer-Tipping Upon Length.—The data in Table 15 show that the result of summer-tipping was to increase the total growth in length of the central leader very materially, if its laterals were included in the measurement. Even if the laterals were not included, the length of the average summer-tipped central leader was fully as great as the length of the untreated central leader.

TABLE 15.—GROWTH IN LENGTH OF SUMMER-TIPPED AND UNTREATED CENTRAL LEADERS, 1924

Variety	Treatment	Length in inches on November 9				
		Below cut	Above cut	Laterals	Total	Average total length
Grimes	Summer-tipped	6	25.5	46.75(3)[1]	78.25	
		6.5	12	36.5 (3)	55	
		8.5	16	14.75(2)	39.25	
		8	16	9.75(1)	33.75	
		11	18	0 (0)	29	
		10.5	17	8.25(2)	35.75	45.17
Grimes	Not summer-tipped	....	....	....	27	
		....	....	....	25	
		....	....	....	24.5	
		....	....	....	21.5	24.50
Jonathan	Summer-tipped	9.75	19.5	27.5 (2)	56.75	
		8	16.5	12.5 (1)	37	
		8.5	14	12.5 (1)	35	
		9.5	12	.5 (1)	22	37.68
Jonathan	Not summer-tipped	....	....	....	26.75	
		....	....	....	23	
		....	....	....	21.5	
		....	....	....	20.5	
		....	....	....	19.5	22.25
Winesap	Summer-tipped	7.75	14.25	11.5 (1)	33.5	
		11	12.5	0 (0)	23.5	
		9	13	11 (1)	33	
		7.5	14.5	9.5 (1)	31.5	
		9	12	3.5 (1)	24.5	
		8.5	14	1.5 (1)	24	28.33
Winesap	Not summer-tipped	....	....	....	28	
		....	....	....	20	24.00

[1]Number of laterals is shown by figure in parentheses.

Effect of Secondaries Developed by Summer-Tipping on Diameter of Leader.—To discover, if possible, any suggestion of a relation between the diameter of the central leader at its base and the presence or absence of laterals, diameters at this point were divided by shoot length. The results are given in Table 16.

The figures representing the relation of the diameter of the central leader to its length are uniform in Grimes and Jonathan trees not summer-tipped and, therefore, appear to be sufficiently representative. A difference between the trees of the two varieties in this relationship can be seen. In the Grimes the diameter of the central leader that bore laterals was greater, relative to its length, than the corresponding value for the central leader without laterals. This increase in diameter, attributable to the growth of laterals, was not found in the Jonathan, where the relation of the diameter to the length of the central leader was the same among both groups of trees. The difference may be a varietal characteristic not to be explained upon the basis of a difference in the time when the growth in length of laterals may have ceased. Most of the laterals were long, considering the fact that their growth

was made after July 20, and they probably did not cease growing until near the end of the season. It is reasonable to assume that, while its laterals are still increasing in length, the new shoot of one variety may lay down more wood than the new shoot of another variety. The slenderness of the Jonathan can be taken as further justification for this assumption.

TABLE 16.—EFFECT OF SUMMER-TIPPING ON GROWTH OF CENTRAL LEADER, 1924

Variety	Treatment	Diameter of central leader 2 inches from base	Length of—		Diameter divided by length of—	
			Central leader[1]	Laterals	Central leader	Central leader and laterals
		cm.	*inches*	*inches*		
Grimes.............	Tipped......	1.05	31.5	46.75	.0335	.0127
		.78	18.5	36.5	.0421	.0142
		.78	24.5	14.75	.0318	.0200
		.70	24	9.75	.0292	.0207
		.79	29	0	.0272	.0272
		.69	27.5	8.25	.0251	.0193
Grimes.............	Not tipped...	.74	27	....	.0274	.....
		.65	25	....	.0260	.....
		.66	24.5	....	.0269	.....
		.60	21.5	....	.0279	.....
Jonathan...........	Tipped......	.85	29.25	27.5	.0291	.0150
		.72	24.5	12.5	.0294	.0195
		.60	22.5	12.5	.0267	.0172
		.59	21.5	.5	.0274	.0268
Jonathan...........	Not tipped...	.76	26.75	....	.0284	.....
		.65	23	....	.0283	.....
		.60	21.5	....	.0279	.....
		.60	20.5	....	.0293	.....
		.54	19.5	....	.0277	.....
Winesap............	Tipped......	.70	22	11.5	.0318	.0209
		.70	23.5	0	.0298	.0298
		.69	22	11	.0314	.0209
		.59	22	9.5	.0268	.0187
		.68	21	3.5	.0324	.0278
		.65	22.5	1.5	.0289	.0271
Winesap............	Not tipped...	.75	28	....	.0268	.....
		.50	22	....	.0227	.....

[1]In the summer-tipped trees, this is the sum of the length of the shoot below and above the point where it was tipped back.

The Winesaps appeared to resemble the Grimes in the effect of the growth of laterals upon the diameter of the leader.

Lateral growth was not, in any of the varieties, so effective in increasing the diameter of the central leader near its base as terminal growth, since the figure representing the diameter and length relationship is low (much below the value for check shoots), whenever the length of the laterals is included.

Location and Number of Branches Developed After Summer-Tipping.—On July 20 it was observed that some of the buds back of the cut on central leaders summer-tipped on July 11 were starting to send out new shoots and that the bud closest to the cut had invariably re-

sumed growth. It would be necessary to use this new shoot to continue the central leader. During the remainder of the summer all but two of the leaders developed additional branches. Three of the eighteen tipped leaders developed two lateral branches and two others developed three.

The shoot from the second bud back of the cut in this test was invariably shorter than the vertical shoot from the bud just back of the cut. Its angle, altho it varied in degree, was usually wide enough to permit its use for the development of a permanent branch. If branches developed from near-by buds still farther from the cut, they were shorter and their angles were wider. Such shoots, when they developed, as a rule promised to make better framework branches because of their wider angle and smaller size relative to the central leader than the branches developed from those buds close to the cut.

Effect of Dormant (1924) Cut on Summer-Tipped Trees.—The effect of the heading back that had been done in 1924 before growth started differed, in ways that have an important bearing on the process of training the tree, from the effect of summer-tipping described above. On many of the two-year trees two or three branches developed near the cut at narrow angles and closely paralleled the central leader. On the one-year trees these laterals often equalled the central leader in length (see Fig. 3). This undesirable effect was the result of a heading-back cut that had been much less severe (at 28 inches) than the usual commercial practice. The effect is shown in Table 17.

That eight of the ten Delicious trees and seven of the ten Golden Delicious had thrown out one or two lateral branches competing with the central leader as the result of dormant pruning at time of planting can be seen in Table 17. To guard against the development of bad forks, it would be necessary to remove such laterals entirely. Less strongly competing laterals might also need removal for the same reason.

A second objection to the dormant heading-back cut was the crowded condition among the branches which it forced into growth. That they were crowded can be realized by allowing an average separation of ¾ inch between them, which is approximately the interval between the buds from which they originated. The vertical space along the whip from which laterals developed did not exceed 7½ inches on any of the trees. If a set of spirally distributed and fairly widely spaced permanent framework branches were to be secured, it would be necessary, sooner or later, to discard all but one of the entire group.

Method Second Year.—In the summer of 1925 more of the trees planted in the spring of 1924 were used to continue the study of sum-

mer-tipping. Points to be studied were the relations between the number of buds which the cut forced into growth and the severity of the cut, and between the number of new shoots and the time when the cut was made. The length of the period after tipping during which new shoots were still appearing was to be observed, as well as the angle and length of the new laterals.

TABLE 17.—DEVELOPMENT OF LATERALS ON ONE-YEAR DELICIOUS WHIPS AFTER DORMANT HEADING BACK, 1924

Variety	Buds forced into growth, counting from cut[1]										Buds developing most vigorous lateral[2] or laterals of equal vigor
	1	2	3	4	5	6	7	8	9	10	
Delicious...	D	X	–	X	–	X	–	–	–	–	2
	X	X	X	X	X	X	X	X	X	–	1, 2
	X	X	X	X	X	–	–	–	–	–	1, 2, 3
	X	X	–	X	–	–	–	X	–	X	1, 2
	X	X	–	–	X	X	X	X	–	–	1, 2
	X	X	–	X	X	X	X	–	–	–	1, 2
	X	X	X	X	X	X	–	–	–	–	1
	X	D	X	–	–	–	X	–	–	X	1, 3
	X	–	–	–	–	–	–	–	X	X	1, 9
	X	X	–	X	–	X	X	–	X	X	1, 2, 3
Golden Delicious	X	X	X	X	X	X	X	X	X	X	1, 2, 3
	X	X	X	X	X	X	–	X	X	X	1, 2, 3
	X	X	X	X	X	X	X	–	–	–	1, 2, 4
	X	X	X	X	X	X	X	X	X	–	1
	X	X	X	X	X	X	X	X	–	–	1, 2, 3
	D	X	X	X	–	X	X	–	–	–	2
	X	X	X	X	X	X	X	X	X	–	1
	X	X	X	X	X	X	X	–	–	–	1
	X	X	X	X	X	X	X	X	–	–	1, 2
	X	X	X	X	X	–	X	–	X	–	1, 2
	D	X	–	–	X	X	X	X	X	X	2, 5
	X	X	X	X	X	X	–	X	X	–	1, 2, 4

[1]Dead buds indicated by D. Buds which developed into branches indicated by X. [2]Indicated by number from cut. When two or more branches (laterals) developed with approximately equal vigor, as indicated by length, the number of the bud from which each originated is given.

All central leaders were cut back soon after they had grown far enough to throw out a branch where wanted. The length of the part of the shoot removed varied from ½ inch to 3¾ inches. It was possible to make some of the cuts on May 26, but the central leaders of other trees had not reached the desired length until early in July. The last cuts were made on July 13. The central leaders of a few trees failed to reach a suitable length. Two of the cuts made on July 13 were made after terminal buds had been formed.

Relation Between Branching and Severity of Summer Cut.—In no case, taking the number of buds forced out on shoots of the same variety cut back on the same date as the basis for comparison, could any relation be seen between the number of buds forced into growth and the length of the shoot removed (Table 18).

Relation Between Branching and Date of Summer-Tipping.—The relation between the number of branches forced out and the date of summer-tipping can also be seen in Table 18. On one variety, the Winesap, and possibly on the Golden Delicious, tipping during the early part of the summer was more effective than when done on July 13. The Jonathan, however, developed many more new shoots from cuts made on June 8 and June 12 than from cuts made either before

TABLE 18.—RELATION OF TIME OF SUMMER-TIPPING AND LENGTH OF CENTRAL LEADER CUT OFF TO NUMBER OF BUDS FORCED INTO GROWTH, 1925

Variety	Date of removal	Number of shoots produced on different trees after removal of different lengths of growing central leader			
		1-1.5 inches removed	1.75-2.25 inches removed	2.5-3 inches removed	3.25-3.75 inches removed
Winesap...........	May 26	2, 2	....	....	....
	June 8	2, 2, 1	2, 2	2, 2, 2	....
	June 12	1, 1	....	....	3
	June 20	......	1	....	....
	July 13	......	....	....	....
Grimes............	May 26	2, 1	....	1	....
	June 8	1, 1	1	1	....
	June 12	1	1	....	....
	June 20	2	....	....	....
	July 13	2	....	1	....
Jonathan...........	May 26	......	2	2	....
	June 8	10, 4	6, 5	....	....
	June 12	5, 5	....	4, 3	....
	June 20	3, 4	2, 3, 3, 3	....	....
	July 13	2	....	....	....
Delicious...........	May 26	......	....	....	....
	June 8	4, 3, 2, 1, 1	....	4	....
	June 12	1	2	....	3, 2
	June 20	2	....	....	....
	July 13	1, 4, 2	....	....	....
Golden Delicious....	May 26	2, 4	5, 4	3	....
	June 8	2, 2, 4, 3, 3	....	....	....
	June 12	2	....	3	....
	June 20	3, 1, 2, 1	....	....	....
	July 13	......	....	....	....

or after these dates. On two varieties, the Grimes and Delicious, the variation in time had little or no effect. It is an interesting fact that the Grimes developed fewer new laterals than any other variety, which is the opposite of its behavior in the previous summer.

A still more important factor, however, in determining the number of branches forced out was individual shoot variation, which entered strongly, irrespective of the time when the cut was made. Variation was strong even in the response of leaders arriving at the same length at the same time. An observation of considerable interest was that all of the Golden Delicious shoots which reached the right length for summer-tipping on June 8 had already sent out from four to ten laterals, altho no other shoots of this or other varieties developed

laterals in that year without summer-tipping. On the whole, it appears that shoot individuality at any one time is more important in determining the number of buds to be forced into growth than the variation in time of tipping. Whether varietal differences that appear in the table are at all constant is problematical because the variety that formed the most lateral shoots in the summer of 1924 formed the least in the summer of 1925, while three of the varieties that formed few laterals in 1924 formed laterals rather freely in 1925.

Relation Between Date of Summer-Tipping and Length of Interval Before Visible Response.—On one of the twelve trees summer-tipped on May 26, a new shoot was forced out within three days. The response of six trees was complete in seven days, as shown by later examinations; it was complete in all twelve trees within ten days. On trees summer-tipped June 8, 90 percent of the buds which finally developed shoots had started into growth within twelve days. Response to later summer-tipping was slower.

Angles of Branches Developed by Summer-Tipping.—Contrary to the result of summer-tipping in 1924, most of the new shoots from the second bud back of the cut competed in vigor with the shoot from the highest bud left and paralleled it too closely to form a good framework. On practically all of the trees of the four varieties a branch with a suitable angle was developed from a bud at a greater distance from the cut than the second bud.

Summary of First Summer-Tipping Experiment.—The most important specific effects observed in the 1924 planting were as follows:

1. The total length of the central leader was increased by lateral shoots which developed during the remainder of the summer after summer-tipping. When only the shoot developed by the bud immediately back of the cut was included, the length of the central leader was not seriously reduced.

2. In contrast to severe dormant pruning, summer-tipping developed very few laterals, and did not necessitate the removal of a large amount of wood to avoid bad forks and a crowded framework.

3. Usable laterals were developed almost invariably. These originated from the second bud from the cut or from buds immediately adjoining.

4. The first bud back of the cut always resumed growth in the same summer and continued the central leader.

5. Under the conditions of the experiment, the same effects were produced by removing ½ or 1 inch from the tip of the central leader as by removing 2½ or 3 inches.

6. The date of summer-tipping (between May 26 and July 13) was a factor in the number of buds responding in some varieties.

7. The resumption of growth, if it occurred within the same summer, could usually be seen within ten days. The rate of response decreased as the season advanced.

8. The results indicated that some condition within the shoot was a more important factor in its response to summer-tipping than the length of shoot removed or the time of removal.

Thus the 1924 experiment demonstrated that summer-tipping was a practicable way to secure lateral shoots at the levels where framework branches were wanted, and that it could probably be used to supplement dormant pruning. At the same time it was evident that further study was desirable, and that the actual training of trees of several varieties and habits of growth was necessary.

SECOND PLANTING

Eighty trees, consisting of 24 Wealthy, 22 Winesap, 12 Transparent, 12 Golden Delicious, and 10 Jonathan, were planted in the spring of 1925. They were well-grown budded one-year whips but had become rather dry in transit from the nursery.

Object.—By dormant heading back and summer-tipping, half the trees were to be trained to a spiral set of four or five framework branches around a central leader. The branches were to be separated by intervals of 8 or 10 inches. Dormant heading back was to be used to force out one, or two if possible, of the lowest branches. One or two more branches were to be developed by summer-tipping. If necessary, this was to be followed by heading back the central leader in the next dormant season.

The heads of the rest of the trees were to be trained to a vase shape. The main framework was to consist of four branches. These were to be developed in the first summer, back of a heading-back cut to be made when the whips were planted. This part of the experiment would be an indication of the relative ease of training, from the start, toward the vase-shaped type, which, as it has been shown, is the prevalent type in the mature orchard. It could be used also to study relations within the head, especially the tendency to replace the central leader after its removal and the effect of its removal upon the direction of the lower branches.

Methods Used and Results Obtained During First Year.—All of the trees, without regard to differences to be introduced into the experiment later, were headed at 36 inches when planted, to avoid the

undesirable effect of a strong heading-back cut. It was thought that this light pruning might result in the development of a number of wide-angled branches, not confined to the space immediately back of the cut. Thruout the planting growth was irregular. Some of the trees grew very vigorously, but some of them grew very poorly, presumably because of their condition upon arrival. At the end of the season it was evident that it would be best, for the sake of uniformity, to start again in the following year by pruning all the trees to whips.

Summer-Tipping

Methods Second Year.—All trees were headed back while dormant to 30 inches, which placed the cut on the 1924 wood at a point about 6 inches below the cut that had been made in April, 1925. All laterals that had been formed during 1925 were removed unless located where they might be used in the permanent framework. In that case they were headed back to within one or two inches of the trunk to overcome the advantage that they would have over the laterals that would develop later.

All of the trees grew well in 1926. Those on which the central leaders made enough growth were summer-tipped on June 18. At that time they were cut back from 1 to 4 inches, the severity of the cut being determined by the length of the shoot and the position where the new lateral was to be located.

On August 10 a second summer-tipping was given shoots which had grown far enough past the point of the first summer cut to form another framework branch. A few which had grown very long were headed back severely, from 3 to 12 inches. On that date, also, the central leaders which had not made enough growth on June 18 for summer-tipping were cut back lightly.

Trees to be trained to the vase shape were not summer-pruned in 1926.

Results of Summer-Tipping During Second Year.—The immediate results of summer-tipping, in forcing lateral buds along the central leader into growth, are shown in Table 19. Varietal and individual differences in growth during the summer of 1926 are also shown.

Varietal differences were again important. The Golden Delicious, Winesap, and Jonathan branched much more freely than the Transparent and Wealthy (Table 19). This was not the same order, however, in which varieties differed in the growth in length of the new shoots to be used as leaders; none of the Golden Delicious leaders made enough growth to be summer-tipped a second time, while many leaders of the trees of the other varieties, including the leaders of all the

TABLE 19.—LOCATION OF BUDS DEVELOPING LATERALS AFTER SUMMER-TIPPING, JUNE 18 AND AUGUST 10, 1925
(Recorded in following dormant season)

Jonathan		Golden Delicious		Winesap		Transparent		Wealthy	
June 18	Aug. 10	June 18	Aug. 10	June 18	Aug. 10	June 18	Aug. 10	June 18	Aug. 10
1, 2, 3[1]	1, 2[2]	1, 2	0	1	1	1, 2	0	1, 2	1
1, 2, 3	0	1, 2, 3, 4	0	1	1	1	0	1	1
1, 2, 3	0	1, 2, 3, 4	0	1, 2	1	1	0	1, 2	1
1, 2	0	1, 2, 3	0	1, 2	0	1	1	1, 2, 3	1
2, 1	1, 2	1, 2, 4, 3	0	1, 2	1	1, 2	0	1, 2	1
....	...	....	...	1, 2, 3	0	1, 2	0	1, 2	1
....	...	....	...	1, 2	0	...	...	1, 2	1
....	...	....	...	1, 2, 3	2, 1, 3	...	...	1, 2	1
....	...	....	...	1, 2	0	...	...	1, 2, 3	1
....	...	....	...	1, 2, 3	0	...	...	1	1
....	...	....	...	1, 2, 3, 4	0	...	...	1	1
....	...	....	...	......	...	...	...	1, 2	1

[1]First, second, and third buds back of cut made June 18 on this tree developed shoots before the close of the same growing season. The shoots varied in length in the order named. [2]First and second buds back of the cut made August 10 developed shoots before the close of the same growing season. The shoots varied in length in the order named.

Wealthys and some of the Winesaps, could be tipped back a second time in August.

All but one of the leaders developed fewer branches after the second summer-tipping than they had developed after the first. Usually only one shoot developed, which continued the central leader. The second summer-tipping this year was done a month later than in 1924, when the difference in time when it was done had made little or no difference in its result.

As in the former test, no difference was observable in the effect of heading back severely and heading back lightly. Wealthys headed back at 3, 6, and 9 inches, each developed only one shoot.

Methods Third, Fourth, and Fifth Years.—The trees were pruned before growth started in the third year by removing all laterals from the trunk which were likely to compete with those to be used in the framework. Weak horizontal laterals were left. At the same time, the strongest permanent framework branches were headed back lightly to give the higher branches, some of which were considerably shorter, an advantage. The central leaders of all trees in this block were cut back very lightly at this time. The trees were not pruned in the summer of 1927.

In the fourth and fifth years, before growth started, all vigorous upright shoots competing with branches selected for the permanent framework were again removed. Weak, horizontal branches were left. An occasional branch was cut back for balance. No summer pruning was done.

Observations After Third Growing Season.—After the dormant pruning of 1928 it was possible to estimate with fair accuracy the importance of the part that summer-tipping in 1926 had played in forming the framework. At that time the age of each main framework branch, the age of the part of the central leader from which it had originated, and its relation to the various heading-back cuts were recorded. Part of these data are summarized in Table 20. On all of these trees the entire lower framework had been formed either on the 1924 whip, to which the trees had been cut back in the spring of 1926, or along the part of the central leader formed in 1926.

About an equal number of the branches of the five varieties originated on the 1924 wood. All of the averages are above one. On most of the trees, however, it was not possible to secure two really suitable framework branches below the point where the whip had been cut back.

Framework branches originating back of the first summer cut were from .6 to 1.3 times as numerous as those originating on the 1924

wood. On the Jonathan an especially large number of laterals originated on this part of the central leader. Fewer laterals were selected from the part of the central leader between the points where it had been summer-tipped the first and second times.

TABLE 20.—ORIGIN OF LATERALS LEFT FOR PERMANENT FRAMEWORK ON TREES BEING TRAINED TO A CENTRAL LEADER, SECOND PLANTING

Variety	Number of trees	Average number branches on 1924 whip	Average number branches on 1926 leader back of—			Total number
			First summer cut (1926)	Second summer cut (1926)	Dormant cut (April 1927)	
Jonathan......	4	1.5	2	.25[1]	.5	4.25
Golden Delicious..	4	1.25	.75	.25[2]	1.75	4.00
Winesap.......	10	1.3	1	.7[3]	1	4.00
Transparent...	5	1.5	1	0[4]	1.25	3.75
Wealthy.......	11	1.3	1	.5[5]	.7	3.50

[1]Two of the four Jonathans had been given the second summer-tipping. [2]One of the four Golden Delicious had been given the second summer-tipping. [3]Four of the ten Winesaps had been given the second summer-tipping. [4]One of the five Transparents had been given the second summer-tipping. [5]All ten Wealthys had been given the second summer-tipping.

TABLE 21.—LOCATION OF LATERALS LEFT FOR FRAMEWORK IN 1927 IN RELATION TO CUTS MADE IN SUMMER OF 1926

Variety	Average number buds between first summer cut and older wood	Number of bud originating lateral counting back from—	
		First summer cut	Second summer cut
Jonathan................	20	(14, 5) (14, 2)[1] (10, 2) (10, 2) (11, 4)	3
Golden Delicious.........	12	2, 2, 4, 4	2
Winesap................	16	7, 5, 5, 3, 6, 2, 9 2, 2	5, 2, 2, 3, 3
Transparent.............	12	(12, 2) 3, 8	....
Wealthy................	15	3, 10, 4, 4, 3, 2, 4, 2, 5, 3, 2	2, 3, 6, 2, 2

[1]Parentheses include two shoots retained from one leader.

To secure the spacing desired, it was necessary on all varieties to use branches back of the dormant cut of 1927.

The importance of summer-tipping in 1926 in developing laterals can be seen more convincingly in Table 21, in which the origin of laterals in relation to the summer cuts is given for individual trees of the five varieties. To locate the lateral in relation to the entire shoot between the first summer cut and older wood, the average total number of buds on this part of the central leader is included in the table.

That buds close to the summer cut have developed usable laterals can be seen in the above table. Three of the Jonathan trees developed suitable laterals from the second bud back of the first summer cut,

and one was developed by another Jonathan from the fifth bud. One Jonathan developed a usable lateral from the third bud back of the point where the leader was tipped a second time. On this variety, which branched naturally from the lower part of the central leader (see Table 21), branches originated also from lower buds (the fourteenth to the tenth from the cut) and only the upper lateral could be attributed to summer-tipping. On the thirty-three trees, twelve permanent laterals have originated from the second bud back of the first summer cut, five from the third bud, six from the fourth bud, and four from the fifth bud.

The effect of summer-tipping in starting buds into growth was continued into the second summer. Sixty percent of the laterals originating within the space covered by the five buds immediately back of the cut made in 1926 made their first growth in 1927.

Observations After Fourth Growing Season.—In order to estimate the success of the dormant heading-back and summer-tipping treatment in training to the central-leader type, all of the trees of the second planting were examined in May, 1930. Balance within the framework, the direction of framework branches, and the amount of competition from misplaced younger branches were taken into consideration. Balance was considered good if little or no pruning was needed to subordinate parts of the tree, keeping in mind, as far as possible, the relationship between the branches and the central leader at later periods. Direction was considered good when the branches were spirally distributed, when they were all sufficiently vertical to make their permanent retention probable, and when they left the trunk at angles wide enough to prevent the inclusion of bark in the crotches. Competition was considered slight if it was necessary to remove very few vertical new shoots.

So far as could be estimated, balance had been secured in all trees with the exception of three of the Winesaps. One of the lower branches in the framework of each of these trees was growing too strongly. The direction of all branches seemed to be good, and very little pruning was needed on any trees to remove competing shoots.

Notes were also taken in May, 1930, on the degree of dominance maintained by the central leader. All trees in this group had been started out with a strong central leader and, since all varieties had been pruned according to the same plan, the maintenance or decrease in dominance of the central leader could be considered varietal. Such information would also indicate the relative dominance that could be given the central leader in starting the tree, if a given relationship between it and the lower framework were to be secured.

Decided varietal differences in the tendency for the central leader to be maintained or suppressed are shown in Table 22. In the Jonathan, Golden Delicious, and Winesap, the tendency was for the central leader to lose its advantage early. If the central leader in these varieties is to be maintained permanently, therefore, the lower branches can be pruned heavily. An alternative would be to use rather weak laterals to start the lower framework and to limit the lower framework branches in number. The fact that this relationship between the central

TABLE 22.—DOMINANCE OR LOSS OF DOMINANCE OF LEADER IN TREES TRAINED TO CENTRAL-LEADER TYPE BY HEADING BACK AND SUMMER-TIPPING: MAY, 1930, AFTER FOUR YEARS' GROWTH

Variety	Number of trees with dominant leader	Number of trees in which dominance of leader is disappearing
Jonathan	0	4
Golden Delicious	1	4
Winesap	2	8
Transparent	4	1
Wealthy	11	1

leader and the lower branches was found in the Golden Delicious as well as in the Winesap and Jonathan indicates that a strong whip, which is characteristic of the former, is not necessarily a criterion of the later dominance of the central leader. The three varieties, it should be pointed out, have the common characteristic of free branching.

In the Transparent and Wealthy the opposite tendency was observed; in these two varieties the central leader maintained its dominance. It can be assumed that in such varieties the tendency is for the eventual suppression of lower branches, which should, therefore, be favored from the beginning of training.

Development of Secondary Laterals Without Summer-Tipping.— On June 18, 1926, at the time of the first summer-tipping, the 1926 central leaders of four of the five Jonathan trees were already sending out laterals. Since the development of laterals in this way may play an important part in heading, the location and length of these laterals were recorded. They are given, together with the length of the interval below each bud, in Table 23.

Several differences can be seen in the behavior of the untipped shoots (Table 23) and of leaders that have been cut back (Table 19). The laterals have been developed from the intermediate instead of the highest buds. At the base of the shoot, internodal lengths were

short, and buds became or remained dormant. The growth rate of the shoot at that time was probably slow. At a distance of 2 to 4 inches from the base of the shoot, where the lowest laterals (secondaries) were formed, the space between buds, the total amount of growth between buds, and probably the growth rate, approached or equaled its maximum. At this point, or near it, the longest laterals were developed. At a point about 8 inches higher, where growth, as indicated by internodal length, started to decrease, lateral development was not evident

TABLE 23.—LOCATION OF LATERALS (SECONDARIES) ALONG CURRENT YEAR'S UNPRUNED CENTRAL LEADER IN RELATION TO BASE AND TO INTERNODAL LENGTHS: JONATHANS, 1926
(All measurements in inches)

Bud No. from base	Tree 1, length of—		Tree 2, length of—		Tree 3, length of—		Tree 4, length of—	
	Internode	Lateral	Internode	Lateral	Internode	Lateral	Internode	Lateral
23	....	.. [1]	.75	0[1]	...	.. [1]	...	.. [1]
22	....	...	.5	0	...	...	...	...
21	....	...	.75	0	...	...	...	...
20	.75	0	.75	0	.75	0	.75	0
19	1	0	.5	0	.75	0	.75	0
18	.75	0	.75	0	.5	0	.5	0
17	1	0	.25	0	.5	0	.75	0
16	.25	0	1	0	1.5	0	1	0
15	1	.25	.5	.25	.25	1	.5	.1
14	.75	1.5	.5	1	1	1	.75	1
13	1	2	1	1	1	1.5	.75	.5
12	.75	2.5	1	1.5	.75	1.5	1	.25
11	1	2.5	.75	2	1	2	1	1.75
10	1	3	.25	2.5	1.5	.25	1.25	0
9	1.5	3.5	1	.25	1	0	1	0
8	1	5.5	1	0	1	.1	1	2.5
7	.5	3.5	1	4.5	1	0	1	2.5
6	1	5.5	1	3.5	.75	0	.75	0
5	.75	0	.5	0	.25	0	.5	0
4	.12	0	.5	0	.12	0	.25	0
3	.12	0	.12	0	.12	0	.12	0
2	.25	0	.12	0	.12	0	.12	0
1	.25	0	.25	0	.12	0	.10	0

[1]Total length of central leaders, May 18: Tree 1, 18 inches; Tree 2, 15 inches; Tree 3, 18 inches; Tree 4, 18 inches.

on the date of the examination, altho buds still higher might have formed laterals before the end of the season. This point was about 6 inches below the tip of the shoot.

Another difference was the wide angle which all of these laterals took with the central leader. In this planting, the formation of laterals without summer-tipping occurred only on long shoots of this one variety. That the Golden Delicious has the same characteristic has already been noted. In both the Jonathan and Golden Delicious varieties it should be possible to take advantage of this habit in the development of laterals for the framework.

Development of Laterals in Year Following Summer-Tipping.—A great deal of variation was observed among the varieties in their de-

velopment of laterals from the central leader in the year succeeding extension. Sometimes these laterals were more suitable in position and angle for framework branches than those formed closer to the summer cut. Altho they were usually shorter, this was sometimes desirable, so that a variety with this tendency strongly developed might

TABLE 24.—POSITION AND ANGLES OF LATERALS DEVELOPED IN 1927 ALONG PORTION OF CENTRAL LEADER FORMED IN 1926

Variety	Bud from which shoot originated[1]		
	Shoot angle 0°-45°	Shoot angle 45°-72°	Shoot angle 72°-90°
Jonathan	1, 2	3	4, 5, 9, 6, 13, 14, 16, 20
	1, 2	3	4, 6, 14, 20, 19, 15, 5, 7, 13
	1, 2	3	14, 12, 18, 19, 21, 17, 15, 13, 11 4, 10, 8
	1	2, 3	5, 6, 8, 11, 7
Golden Delicious	1, 2	3	4, 5, 9, 6, 13, 14, 16, 20
	1, 2, 3, 5	4, 6, 8, 10	9
	1, 2	3, 5	4, 6, 10, 9, 8, 6
	1, 2, 3	....	6, 9, 8, 5, 4, 14, 11, 19, 20, 13
Winesap	1, 2	3	4
	1, 3, 2	....	4
	1	....	2, 3, 9, 6, 8, 7, 5, 4
	1, 2, 3	4	6, 25, 14, 24, 11, 8, 7, 9, 12, 15, 16, 19, 17, 21, 20, 18, 30, 29
	1	2	3, 4, 7, 9, 8, 10, 12, 11, 13, 15
	1, 2, 3	4	6, 10, 7, 8, 11, 12
	1, 2	3	7
	1, 2	4	7, 6, 13, 10, 8, 5, 9
	1, 2, 3	4	5, 6, 16, 8, 7, 9, 11, 12, 13
Transparent	1, 2	13	10, 15, 16
	1, 2, 3	4, 5	....
	1, 2, 3	....	4, 7, 5
	1	....	8, 9
Wealthy	1	2	3, 4
	1, 2, 3	5, 6	....
	1, 2, 3	4	....
	1, 2	3	4, 9
	1	3, 6	4, 5
	1, 2, 3, 4	5	....
	1, 2, 3	4, 5	....
	1, 2, 3	7, 4, 6	....
	1, 2, 3	5, 4	7
	1, 2, 3	6, 7, 5	....
	1, 2	5, 3, 10	....

[1]Numbers stand for number of bud on 1926 shoot counting back from point where it was cut back in April, 1927. These numbers are arranged in order of length of 1927 laterals.

be somewhat differently trained than one without it. To study varietal differences in this respect, the 1927 laterals developing along the part of the central leaders formed in 1926 were used. These leaders had not received the customary severe cutting back before the commencement of growth in 1927, but had been tipped back lightly at that time. Varietal differences in branching are brought out in Table 24. In these data the shoots are separated according to their angle with the parent branch (the part of the central leader which grew in 1926), as well as by their distance from the cut.

Most of the Jonathan, Golden Delicious, and Winesap trees were prolific in the formation of laterals from the lower buds on the shoot developed as a central leader the previous year (Table 24). These laterals almost invariably took a wide angle. Not all of them, however, were short. Altho on most trees length and distance from the cut were roughly associated, on several trees the arrangement of shoots of wide angle was very irregular. Whether or not the terminal cut was responsible for the development of lower shoots is not indicated by these measurements. Other observations indicate that they would have developed without it. The contrast between these three varieties and the Transparent and Wealthy is very striking. On all varieties, however, it appeared that laterals originating from the trunk in the second year could be made a valuable source of framework branches, to supplement those obtained in the first year.

Summary of Results of Summer-Tipping in Second Planting.—

1. There was less response to late tipping (August 10) than to early tipping (June 18). Even on the later date, however, the highest bud always grew, the shoot taking an upright direction.

2. More laterals, which were finally used as framework branches, developed from the second bud back of the cut than from lower buds, altho shoots from the third, fourth, and fifth buds were selected on many trees.

3. Suitable laterals were developed in the second year and were used in the framework of some of the trees.

4. Usually only one suitable branch could be obtained back of the customary dormant heading-back cut.

5. On some of the trees, four branches, suitable in spacing, distribution, and angle, were obtained by the customary dormant cut and by tipping the central leader twice in the summer. Where this was possible, the main framework was obtained in one year. On most trees, it was necessary to utilize another year's growth of the central leader.

6. Three years after heading back the whip a second time, light pruning to remove a few competing branches was still needed on most of the trees. The period of heavy pruning was over. At that time, the framework branches of almost all the trees appeared to be well balanced and promised to be permanent. The central leader had become coordinate in strength with the lower branches in Jonathan, Golden Delicious, and Winesap trees, but was growing more strongly in the Transparent and Wealthy trees. This was the fourth year after setting out. The trees had been headed back to whips before growth

started the second year, because of irregular growth the preceding year.

Training to Vase Shape

Methods Second Year.—Because of the failure of the trees to grow uniformly in the first year after planting, those to be trained to the vase-shaped type were headed back to 30 inches before growth started. Poorly placed branches were removed, and those left were

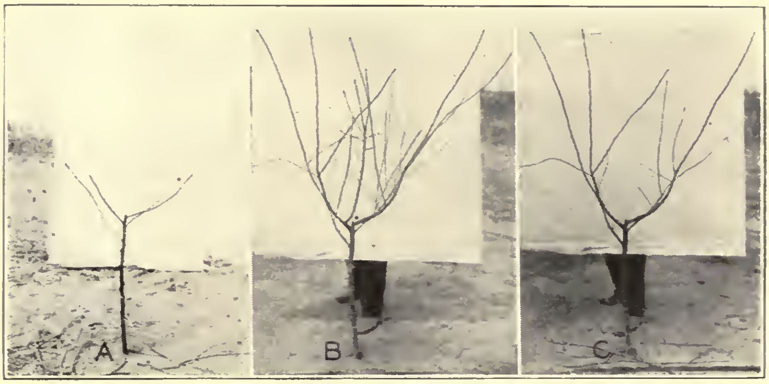

FIG. 25.—WINESAP TREE BEING TRAINED TO VASE-SHAPED TYPE

The central leader was removed and four laterals were left for the permanent framework in April of the second season (*A*). In the following summer the vigorous upright branches toward the inside of the tree were forced out to replace the central leader, an inevitable result in vigorously growing young trees when the inner part is pruned too heavily (*B*). These inner branches were removed at the end of the second season to maintain the vase-shaped type (*C*). By comparing the direction of the lower parts of the framework branches in *A* and *B*, it can be seen that the older wood has taken an upward direction in the year after its formation and that the angle has decreased. See also Fig. 26.

cut back to a length of 1 or 2 inches. They were given no other pruning during the year.

Methods Third Year.—The trees being trained to a vase shape were thinned to four branches with as wide a vertical separation as possible. The best selection that could be made left an average space of only 6.4 inches between the highest and lowest of the four branches. There were no constant varietal differences. The central leader was removed above the highest branch left, and the other three were headed back for balance, taking into consideration the possibility that the highest branch, because of its location and more upright position, might assume the place of a central leader (Fig. 25, *A*). These trees received no summer pruning.

Methods Fourth and Fifth Years.—The trees were pruned only when in dormant condition. At that time vigorous branches growing toward the center were removed (Fig. 25, *B, C*).

Observations in May, 1930, on Results of Pruning to Vase Shape.—In many of the vase-shaped trees, the highest one of the four

FIG. 26.—TREE STARTED AS VASE FORM CHANGING TO CENTRAL-LEADER TYPE
The highest selected framework branch has assumed a dominant vertical position and is forming a central leader.

branches selected three years before to form the permanent scaffold had assumed a comparatively vertical direction, and in reality was constituting a central leader (Fig. 26). This had occurred in two of the five Jonathans, in two of the six Golden Delicious, in four of the nine Winesaps, in four of the five Transparents, and in seven of the eleven Wealthys. The behavior of the first three varieties is interesting in view of the fact that in trees of these varieties started with a cen-

tral leader, the central leader was no longer dominant after three years.

The result of pruning to a vase shape, therefore, was often a central-leader tree bearing three main framework branches, which left the trunk at approximately the same point

Comparison of Training to Central Leader and to Vase Shape.—In pruning to the vase shape, it was necessary to remove upright branches which originated on the main framework and tended to fill up the center. In pruning to the central-leader type, with a limited

TABLE 25.—COMPARISON OF AMOUNT OF PRUNING REQUIRED TO MAINTAIN CENTRAL-LEADER AND VASE-SHAPED TREES

Variety	Average weight of wood removed	
	Vase-shaped tree	Central-leader tree
	ounces	*ounces*
Jonathan	3.0	4.7
Golden Delicious	5.5	7.7
Winesap	5.7	5.2
Transparent	1.6	2.5
Wealthy	3.0	2.7

TABLE 26.—EFFECT OF TYPE OF HEAD ON AMOUNT OF GROWTH MADE BY TREE DURING FIRST FOUR YEARS, APRIL, 1925, TO APRIL, 1929

Variety	Average trunk diameter of 4-year-old tree—	
	Trained to vase-shape	Trained to central leader
	inches	*inches*
Jonathan	1.3	1.3
Golden Delicious	1.4	1.4
Winesap	1.4	1.5
Transparent	1.1	1.2
Wealthy	1.3	1.3

number of main branches considerably more widely spaced than they would have been naturally, most of the pruning was to remove competing branches originating on the trunk.

Wood Removed, April, 1929.—The comparative severity with which it was necessary to prune the trees trained by the central-leader and vase-shaped systems is shown in Table 25.

Variation among trees of each variety was high, so that the difference between the treatments does not seem to be significant. The variations among varieties, since the averages for the two treatments are fairly close and since more trees are included in each average, have more significance. It was necessary to prune the three varieties which branched freely, Jonathan, Golden Delicious, and Winesap,

more heavily than the Transparent and Wealthy, which did not branch freely.

Comparative Sizes of Trees in April, 1929.—The best available way to estimate the effect of the two systems of training upon size was trunk growth. This was taken at a point 12 inches from the ground. Average trunk circumferences at this point are shown in Table 26.

Altho there seem to be differences between varieties, the data do not appear to show any significant differences in the effect upon growth of the method of pruning (Table 26). The average individual gain in the Winesap that started with the open center was .14 inch; in the central-leader Winesap it was .12 inch. Corresponding increases in the Wealthys were .18 and .12 inch. Variations between individuals of the two varieties were so great that the differences may not be significant. (The figures are not suitable for the calculation of probable errors.)

THIRD PLANTING

Disbudding and summer-tipping were continued in the third lot of trees, which was set out in April, 1928. These trees were also used to test the possibility of starting the framework with an even lighter heading-back cut, since the earlier tests had shown that the standard commercial heading-back cut was unnecessarily severe. Other trees were set out without any heading back at all; the framework was to be selected at the end of the first year. The check trees were not pruned.

The serious reduction in longevity which often results from the heading-back cut, and the fact that heading back, altho it is customary, has not invariably been found necessary, have been pointed out.

Since the practice of heading back on transplanting is based partly on the conception that trees without heading back will not grow, the first new problem for study would be growth in the first year. If the trees failed to grow well then, the set-back might be overcome in the second year or later, so that growth for at least two years should be recorded. The distribution of laterals would be expected to be different from the distribution secured by conventional methods; the details of securing good spacing, direction, angles, and balance within the branches and with the central leader would all be new, and would therefore need to be recorded. It would probably be unnecessary to remove branches to avoid bad forks.

Since work in the earlier plantings had shown that varietal differences were likely to be important, ten varieties were included in the third planting. These were Winesap, Stayman, Grimes, Rome, Willow, Jonathan, Starking, Duchess, Transparent, and Golden Delicious.

Thirty-two trees of each variety were planted. All trees were one-year whips. The trees of most varieties averaged from 42 to 48 inches in length, and all were in good condition when set out. As in the preceding experiments, the trunks were measured at a height of about one foot, and the point of measurement was marked with paint. Four methods were compared; eight trees of each variety were used for each treatment.

Methods First Year

Disbudding.—The weaker whips were headed back 1 or 2 inches, and the stronger whips 4 or 5 inches, while still dormant. This placed the average height of the cut at 37 to 48 inches above the ground, the average varying with the variety. A few individuals were headed at 52 to 54 inches. The selection of groups of buds or short shoots was made on May 23, when the more vigorous trees had formed a few

FIG. 27.—TREE BEING TRAINED TO MODIFIED CENTRAL LEADER BY DISBUDDING TO GROUPS OF BUDS

The Grimes tree at the left was planted as a whip one year before this photograph was taken. It was headed back slightly at planting time and disbudded to groups of three or four buds at the points indicated by the arrows. The same tree after pruning at the end of the first season is shown at the right. Four permanent framework branches have been located. The central leader was not headed back.

shoots 2 or 3 inches long. The lowest group was left at a height of about 20 to 24 inches from the ground, where the lowest framework branch was to be started. The other groups were spaced at intervals of 6 or 8 inches. Because of the length of the whips, three to five groups of buds or shoots could usually be left, including the cluster of short shoots at the top, which was to provide a central leader and one framework branch. Disbudding was done with a sharp knife. During

FIG. 28.—TREE BEING TRAINED TO MODIFIED CENTRAL LEADER BY DORMANT PRUNING AND SUMMER-TIPPING OF CENTRAL LEADER

The Winesap at the left was planted as a whip one year before this photograph was taken. The whip was only slightly headed back. As a result, strong laterals originated far below the light heading-back cut. The short lateral (indicated by arrow) was forced out on the central leader by summer-tipping. The same tree after pruning at the end of the first season is shown at the right. Four framework branches have been located, three on the long whip left at planting and one by summer-tipping.

the summer, shoots from buds that had been missed were removed. A tree trained by the disbudding method is shown in Fig. 27.

Summer-Tipping.—The whips were headed back lightly as in the disbudding treatment. The vertical lateral competing with the shoot which was to continue the central leader was removed at the time when the central leaders were summer-tipped. All other laterals were permitted to grow thruout the summer. The central leader was invariably continued by a shoot arising just back of the dormant cut, usually from the first bud, tho occasionally from the second and rarely from the third. The competing shoot arose from the bud immediately back of the one continuing the central leader. All of the trees in this part of the experiment, except the Duchess trees, one Rome, one

Transparent, and one Golden Delicious, had made enough growth to be summer-tipped on June 22. The remainder were summer-tipped on July 17.

The length of the central leaders of most of the trees varied from 6 to 10 inches when they were summer-tipped. The length of the cut varied from 1 to 3 inches. The point where a central leader was cut back depended upon its vigor and the position of the bud which was to be forced into growth. Long shoots were usually cut more severely than short shoots, so that the interval between branches would not be too great. It was assumed that the third and fourth bud back of the cut would sometimes develop more suitable laterals than the second bud, because they would have wider angles and the proper degree of subordination. One of these could be used, even if they did not appear until the second summer as in the second planting. The cut was therefore made far enough out to leave two or three buds between the cut and the bud which was to develop the framework branch. A tree developed by the summer-tipping method is shown in Fig. 28.

FIG. 29.—FRAMEWORK SELECTED ONE YEAR AFTER PLANTING

One year after planting as an unpruned whip, the four lower framework branches were selected. The above photograph was taken in June of the third season after planting.

Selecting Framework One Year After Planting.—The trees in this lot were treated just like the check trees during the first season. The whips were planted without pruning and allowed to feather out and grow during the first year without any pruning treatment. During the first dormant season after planting, a selection of the best possible framework was made. A Golden Delicious tree trained by this method is shown in Fig. 29.

Check Trees.—None of the trees to be used as checks were pruned in any way during the year, either on planting or during the summer.

Results First Year

The appearance of the trees thruout the summer showed that transplanting without heading back had been a success. Most of the trees

made a vigorous growth, altho there were very considerable individual variations. Only one tree among the 160 unpruned trees of the ten varieties was lost. This was a Duchess. Since two other trees of the same variety, which had been lightly headed back, also died, the failure of this one cannot be attributed definitely to the lack of pruning. The three trees failed to leaf out.

Increase in Trunk Diameter.—Measured by the increase in trunk diameter, the trees of all varieties made about an equal growth during the first summer regardless of differences in treatment. Variation

TABLE 27.—INCREASE IN TRUNK DIAMETER IN FIRST GROWING SEASON OF DISBUDDED, SUMMER-TIPPED, AND UNPRUNED TREES, 1928
(All measurements in centimeters)

Variety	Light dormant heading back in 1928		No pruning in first season	Checks unpruned
	Disbudded	Summer-tipped		
Winesap	.544 ± .037	.484 ± .021	.650 ± .028	.600 ± .024
Stayman	.600 ± .025	.610 ± .035	.670 ± .045	.508 ± .026
Grimes	.501 ± .024	.482 ± .024	.556 ± .030	.469 ± .027
Rome	.359 ± .039	.359 ± .020	.330 ± .032	.250 ± .021
Willow	.368 ± .029	.485 ± .034	.450 ± .021	.460 ± .026
Jonathan	.380 ± .022	.391 ± .019	.440 ± .024	.410 ± .018
Starking	.451 ± .024	.478 ± .027	.452 ± .027	.556 ± .036
Duchess	.332 ± .017	.322 ± .018	.339 ± .025	.408 ± .024
Transparent	.316 ± .028	.235 ± .030	.340 ± .020	.245 ± .018
Golden Delicious	.487 ± .023	.469 ± .020	.539 ± .023	.573 ± .034

TABLE 28.—AVERAGE NUMBER OF USABLE BRANCHES LEFT IN APRIL, 1929, ABOVE A HEIGHT OF ABOUT 24 INCHES ON PRUNED AND UNPRUNED TREES

Variety	Light dormant heading back, April, 1928		Checks unpruned, 1928
	Disbudded, May, 1928	Summer-tipped, 1928	
Winesap	3.4	2.4	2.8
Stayman	2.4	2.9	3.3
Grimes	3.1	3.5	4.1
Rome	3.3	3.0	3.3
Willow	2.4	2.4	2.5
Jonathan	3.0	3.6	3.4
Starking	2.4	2.8	2.4
Duchess	1.4	2.0	1.3
Transparent	1.6	1.3	1.0
Golden Delicious	3.4	3.6	3.5

within plots was sufficient, in all varieties, to render the significance of differences in averages doubtful. Plot averages with probable errors are given in Table 27.

The relatively great importance of individual variation can be seen by comparing the averages in the last two columns of Table 27. The differences between these averages are often as wide as the differences between the averages representing pruned and unpruned trees.

Number of Usable Laterals.—The average number of 1928 laterals which met, more or less completely, the requirements of spacing, direction, and angle that seemed to be necessary for permanence, are shown in Table 28.

At least half of the number of usable laterals needed to form a framework of four or five branches had been secured on most of the varieties in the first year by all of the methods (Table 28). As far as

FIG. 30.—GROWTH RESPONSE THE SECOND YEAR AFTER DISBUDDING
A Transparent whip which responded very poorly the first year after disbudding is shown at the left. The tree feathered out nicely the next year, forming the three well-placed branches shown on the right. See also Fig. 34.

the figures show, there was no consistent difference in favor of disbudding or summer-tipping. Eight of the ten varieties responded satisfactorily to all the treatments the first season. On Duchess and Transparent, however, the total number of suitable framework branches produced in the first year was no higher than could be expected from the standard heading-back cut (Fig. 30).

Effect of Light Heading-Back Cut Upon Location of Branches.—The immediate effect on the trees to be summer-tipped and disbudded

of light heading back before growth started was to increase the growth of several shoots near the cut, especially in certain varieties. Varieties in which this tendency was most pronounced during the early summer were the Stayman, Rome, Duchess, and Transparent. In these varieties, however, the tendency was for longer shoots to form nearer the tip than lower down, even on the trees not headed back. The light heading back did not result in the suppression of laterals on the lower part of the trunk (Fig. 31). No difference could be observed in the development of laterals on the lower part of the trunks of trees headed back when dormant as a part of the summer-tipping experiment and on the lower parts of the trunks of unpruned check trees.

FIG. 31.—UNIFORM LATERAL FORMATION RESULT OF LIGHT HEADING BACK

This Rome, planted as a whip one year before the photograph was taken, was lightly headed back. The domination of large upper branches was avoided. The arrow points to a lateral located by summer-tipping.

Irregularity in Branching.—The factor of most importance in training that could be observed the first summer after planting the whip was an irregularity in the location of lateral growth, which was not related to height. This tendency for localized growth was extreme in the Rome and Transparent, on which there frequently occurred along the whips areas where no new shoots were formed (Fig. 30). On the Grimes and Golden Delicious a quite uniform set of laterals was developed, and there were no areas along the trunk upon which the buds remained dormant. It should be especially easy to start the framework of the latter type of tree by any good method.

Methods Second Year

All vigorous first year (1928) laterals not to be used in the permanent head of the three lots of pruned trees were removed in the dormant season of 1928-1929. A few framework branches which promised to form too large a part of the framework if left unpruned were headed back. No central leaders were cut back then or during

the succeeding summer. On all of the pruned trees a final selection of laterals was made at the end of the second growing season and all other vigorous branches were removed. The pruning treatment at this time is illustrated on Grimes in Fig. 32 and on Jonathan in Fig. 33.

Results Second Year

Increase in Trunk Diameter.—The average increase in trunk diameter is given for each treatment in Table 29.

None of the three pruning treatments produced a difference in the

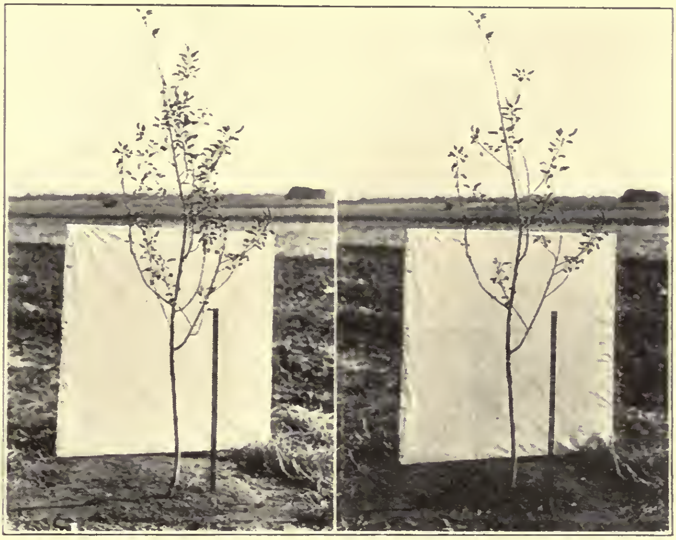

FIG. 32.—APPEARANCE OF DISBUDDED TREES AT END OF SECOND SEASON
The Grimes at the left, trained by disbudding to groups of buds, was photographed before pruning in November, 1929. The same tree is shown at the right after pruning. Five or six well-distributed, widely spaced framework branches with wide angles have been located in two years. Note that the central leader was not headed back. No pruning for balance was necessary. It will not be difficult to train this tree to a modified central-leader type.

second-year average increase in trunk diameter that can be considered significant within any one variety (Table 29). This is in spite of the fact that several different treatments had been introduced before the second growing season. The first treatment had been disbudding the whips to groups of three or four buds, in contrast to letting shoots develop from any or all buds. The second had been slight heading back at planting in contrast to no pruning whatever. The third had been summer-tipping the central leader during the first summer. The fourth treatment, and possibly the one which might have been ex-

TABLE 29.—GROWTH DURING 1929 AS INDICATED BY INCREASE IN TRUNK DIAMETERS
(All measurements in inches)

	Summer-tipped		Disbudded		Framework selected one year after planting of unpruned whip		Checks unpruned	
	Average	C. V.[1]	Average	C. V.[1]	Average	C. V.[1]	Average	C. V.[1]
Winesap	.424 ± .034	33.7	.376 ± .077	19.1	.384 ± .031	33.6	.455 ± .0271	24.7
Stayman	.596 ± .034	23.8	.664 ± .051	32.5	.610 ± .029	19.5	.684 ± .023	13.3
Grimes	.589 ± .029	21.0	.568 ± .054	40.2	.649 ± .041	26.6	.729 ± .045	24.3
Rome	.276 ± .010	15.3	.267 ± .028	43.6	.239 ± .003	4.8	.386 ± .024	26.5
Willow	.482 ± .034	30.0	.440 ± .016	15.6	.400 ± .030	31.5	.582 ± .047	31.6
Jonathan	.449 ± .024	22.6	.459 ± .024	22.4	.532 ± .027	21.7	.596 ± .039	27.2
Starking	.444 ± .024	21.6	.438 ± .032	29.3	.430 ± .025	37.0	.520 ± .041	33.1
Duchess	.728 ± .037	21.2	.784 ± .010	5.1	.843 ± .037	18.6	.940 ± .032	14.5
Transparent	.628 ± .031	20.5	.420 ± .019	17.7	.686 ± .046	28.3	.722 ± .037	21.5
Golden Delicious	.628 ± .022	14.9	.468 ± .027	20.7	.580 ± .033	23.8	.742 ± .036	20.4

[1]Coefficient of variability.

pected to produce the greatest effect, had been the limitation of the number of laterals at the beginning of the second year, in contrast to permitting all laterals to grow. The greater increase in trunk diameter of entirely unpruned trees of all varieties seems to be significant.

Variability has not been decreased or increased by pruning as far as the data in Table 29 show. This is perhaps associated with its

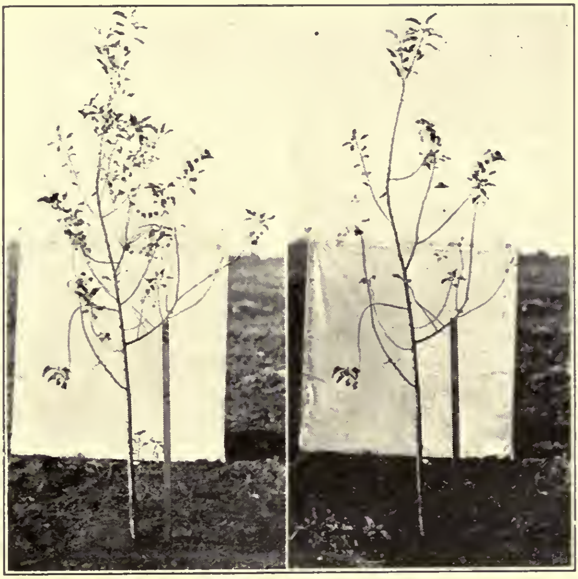

FIG. 33.—JONATHAN BEFORE PRUNING (LEFT) AND AFTER PRUNING (RIGHT)
Five good framework branches have been secured in two years. Note that the central leader was not headed back. No pruning for balance was necessary, and it is not likely that any pruning for this purpose will be needed in the future. Horizontal slow-growing laterals were left on the trunk to increase the total growth of the tree and to decrease the effect of the wind. Such laterals will not form framework branches on this variety.

negligible effect upon growth. However, even severe cutting-back does not necessarily produce uniformity. A lot of thirty vigorous Delicious trees, which had grown for two years in the orchard at Urbana, cut back nearly to the ground in April, 1928, have made very irregular growth.

Number of Usable Laterals.—Practically all of the pruned trees in the experiment had formed at least four suitable laterals by the end of the second summer (Fig. 32). At this time it was possible to discard a few of the two-year branches, substituting, on account of better spacing, direction, angle, or balance, laterals which had originated di-

rectly from the trunk or from short spurs during the preceding growing season. The average number of two-year branches among the lowest three left for the framework on the pruned trees, and those most suitable for the framework on the unpruned trees, are shown in Table 30. The number of one-year laterals left among the lowest three

TABLE 30.—AVERAGE NUMBER OF TWO-YEAR LATERALS RETAINED AMONG THREE LOWEST FRAMEWORK BRANCHES OF PRUNED AND UNPRUNED TREES AFTER SECOND SEASON'S GROWTH, NOVEMBER, 1929

Variety	Summer-tipped	Disbudded	Framework selected one year after planting of unpruned whip	Checks unpruned
Winesap	2.9[1]	2.7	2.1	2.5
Stayman	2.5	2.6	2.6	2.6
Grimes	2.9	2.6	2.0	1.9
Rome	2.8	2.9	1.9	2.8
Willow	2.0	2.3	1.7	2.0
Jonathan	2.9	2.9	2.3	2.3
Starking	2.1	1.9	1.0	1.6
Duchess	.9	1.4	.1	.5
Transparent	1.5	.8	1.0	1.0
Golden Delicious	2.4	2.6	2.0	2.6

[1]The remainder of the three laterals on each tree are one-year laterals.

is, in each case, the difference between three and the number given in the table.

In making comparisons of the data in Table 30, it should be borne in mind that laterals on unpruned trees were often inferior, in one or more essential ways, to laterals selected among the pruned trees. With this allowance, it will be seen that on the unpruned trees the number of more or less suitable two-year laterals approximated, on some varieties, the number retained on pruned trees. The effect of the pruning treatments have therefore been to make the laterals more suitable, rather than to increase their number.

In certain varieties, specifically the Duchess and Transparent, and to a less degree the Starking and Willow, laterals formed the second year after planting were often more suitable for framework branches than laterals developed the first year, regardless of treatment (Fig. 34). This fact is significant because it shows that it is not necessary to head back the tree to force out lower laterals if they are not formed in sufficient number the first year. Altho the removal of a part of the laterals along the summer-tipped and disbudded trunks may have forced buds and spurs into growth the second season, the unpruned trees also sent out new laterals in the second year. Since usable laterals developed in all varieties the second year, pruning for this purpose was not essential.

Intervals Between Laterals.—Because one of the objects of the

investigation was to avoid the crowded condition and irregular spacing resulting from a heading-back cut, the average spacing secured by the three methods of pruning is of interest (Table 31). The spacing which might have been secured at this time among the less suitable laterals of the unpruned trees is also shown. Intervals between the first and second and the second and third laterals selected for the permanent framework are averaged regardless of the year of origin.

FIG. 34.—LATERAL FORMATION ALONG TWO-YEAR TRUNK

A Duchess which did not respond satisfactorily to disbudding the first year is shown at the left. This tree, however, is an exception in these experiments. The same tree, in its second year, is shown at the right. The lowest framework branch is a one-year shoot which has replaced a two-year lateral 6 inches higher up on the same side. The few trees which did not form a sufficient number of well-placed laterals in the first year did so in the second. See also Fig. 30.

Taking all varieties into consideration, no indication of a consistent difference between the spacing of the lower branches of pruned and unpruned trees is seen in the data in Table 31, except, perhaps, a slightly closer spacing among the summer-tipped trees. Variability in spacing was not affected by pruning, and remained an outstanding characteristic of the trees of all varieties regardless of the treatment. It is likely that in all cases this variation can be attributed to variation among the whips at the time they were set out. This is certainly true among the unpruned trees. Among the disbudded trees, it can prob-

ably be accounted for largely by the variation, from one tree to another, in the spacing of the groups of buds left in disbudding which, in turn, depended upon the characteristics of the whip.

Angles of Three Lowest Selected Laterals.—Branches suitable for use in the framework must not only leave the trunk at an angle wide

TABLE 31.—AVERAGE INTERVALS IN INCHES BETWEEN FIRST AND SECOND AND SECOND AND THIRD PERMANENT FRAMEWORK BRANCHES, NOVEMBER, 1929

Variety	Summer-tipped		Disbudded		Framework selected one year after planting of unpruned whip		Checks unpruned	
	Aver.	C. V.[1]	Aver.	C. V.[1]	Aver.	C. V.[1]	Aver.	C. V.[1]
Winesap	6.1	17	7.4	39	8.3	39	9.2	60
Stayman	7.4	41	6.4	37	8.7	55	10.1	51
Grimes	7.6	38	8.7	38	8.4	39	9.9	51
Rome	7.5	51	9.9	25	13.2	36	8.5	33
Willow	7.0	49	6.6	35	7.3	37	7.4	31
Jonathan	7.6	49	10.0	24	8.9	35	9.4	34
Starking	7.4	43	9.5	45	9.5	31	8.3	29
Duchess	7.2	32	9.2	45	8.1	57	10.0	39
Transparent	8.6	45	8.6	46	7.9	50	7.6	40
Golden Delicious	7.6	23	8.4	48	7.6	31	7.1	41

[1]Coefficient of variability.

TABLE 32.—AVERAGE ANGLES BETWEEN FRAMEWORK BRANCHES AND TRUNK MEASURED 3 INCHES AND 12 INCHES FROM CROTCH, NOVEMBER, 1929

Variety	Summer-tipped		Disbudded		Framework selected one year after planting of unpruned whip		Checks unpruned	
	3 inches	12 inches	3 inches	12 inches	3 inches	12 inches	3 inches	12 inches
Winesap	54°	45°	53°	43°	47°	36°	47°	41°
Stayman	51	40	54	45	54	41	48	38
Grimes	60	46	55	42	58	43	58	40
Rome	54	29	44	25	48	28	49	26
Willow	48	36	45	29	46	37	45	34
Jonathan	57	41	56	38	56	43	57	45
Starking	45	35	43	31	50	37	45	35
Duchess	45	33	48	35	53	35	49	35
Transparent	50	29	46	28	49	32	46	27
Golden Delicious	47	30	49	26	49	33	50	35

enough to prevent the inclusion of bark within crotches as the tree grows, but must assume an upright direction within a short distance of the trunk. In general, it can be assumed that a drooping or horizontal direction is an indication of a lack of present and future vigor. It is especially important, in such drooping varieties as the Jonathan and Winesap, to select only branches which tend toward the vertical for the permanent framework. In the more vertical varieties like the Transparent, Starking, and Golden Delicious a selection for an upright direction is not so important. Varietal differences in this respect are indicated in Figs. 35 and 36.

Average angles between the framework branches and the trunk are given in Table 32. They were measured at a point close to the trunk and at a second point sufficiently distant from the trunk to indicate the future direction of the branch.

That laterals secured by either method of treatment left the trunk at rather wide angles and took a more nearly upright direction at 12 inches is shown by the data in Table 32. A tendency toward a correlation can be seen within averages at 3 inches and at 12 inches in most varieties in spite of the small differences. This tendency becomes more pronounced if branches from unpruned trees are excluded, probably because of the irregularities in the unpruned trees already mentioned. The tendency for the branch to become vertical depended much more upon the variety than upon pruning, or the method of pruning.

FIG. 35.—ANGLES IN UPRIGHT VARIETIES

Laterals with very wide angles later become sufficiently erect for framework branches only in upright varieties, such as Starking.

This varietal difference can be brought out by comparing Rome, Transparent, and Golden Delicious with Willow, Starking, and Duchess. On the average, branches of the former varieties assumed the more nearly vertical direction at 12 inches, altho they left the trunk at about the same angle. Averages of angles at 3 inches of all Rome, Transparent, and Golden Delicious branches are 49, 48, and 49 degrees respectively; at 12 inches the angles are 27, 29, and 31 degrees. At 3 inches the average angles for Willow, Starking, and Duchess laterals are 46, 48, and 48 degrees; at 12 inches the average angles of all branches of each of these three varieties is 34 degrees. That there was no consistent difference between the branches of pruned and unpruned trees in their tendency to assume the vertical is of considerable importance in training because it indicates that wider angles are not to be secured at this stage, if they are wanted, by allowing extra branches to grow temporarily.

Balance of Three Lowest Selected Laterals.—The remaining factor to be considered in the framework secured at the end of the second year's growth is balance, both within the lower part of the framework and between the lower and upper parts. That the effect upon the whip

of the customary strong heading-back cut is to produce strong laterals just back of the cut and weak laterals lower down has already been pointed out (Fig. 3). The result of this cut is poor balance within the lower framework if the attempt is made to retain a lower and a higher lateral resulting from this treatment. The misconception that exists in regard to the effect of cutting the whip back lightly, or not at all, instead of heavily, has also been indicated.

FIG. 36.—ANGLES IN DROOPING VARIETIES

The Jonathan frequently produces drooping laterals which are not likely to persist. In such varieties only fairly upright laterals should be selected for framework branches.

The effect of the three methods of pruning upon balance within the lower framework could be estimated in various ways. The way chosen was to determine the difference between the diameter of each of the three lowest laterals of each tree and the average of these three. Since these differences were in units of length, they were changed to percentages by dividing each difference by its corresponding average. The three differences were then averaged, which gave comparable figures representing each tree, with zero representing an equal diameter in all three branches. As an example, the diameters of the three lower branches of one Golden Delicious tree were .42, .70, and .68 centimeter. The average was .60 centimeter and the differences were .18, .10, and .08. The average difference was .12 centimeter, which divided by .60 gave an average difference of 20 percent. The averages obtained in this way were in turn averaged to represent each pruning treatment within each variety and, finally, to represent each treatment within the entire planting. Because of the variation in tree averages, the data are not sufficient to indicate differences in the results of any of the treatments, or differences between the balance to be secured by any of the three methods of pruning and the balance within the framework of the unpruned trees. Average differences in diameter for all the trees of all varieties were as follows: summer-tipped, 14.96 percent; disbudded, 15.48 percent; the trees pruned after one year, 15.75 percent; and check

trees unpruned, 14.34 percent. That a better balance was not secured on pruned trees than on check trees might, perhaps, be surprising if it were not for the fact that it was possible, because of the free branching of most of the check trees, to select laterals of quite uniform size. In the trees pruned by any of the methods, and in the check trees, the effect of the conventional heading-back cut, which is to destroy balance among branches so widely separated, had been avoided.

Balance in the check trees and in the trees pruned only after one year's growth was, however, secured by using somewhat smaller branches. The mean diameter of the laterals left on trees that had been pruned after one year was .565 ± .009 centimeter. The corresponding diameter for the most suitable branches on the unpruned

TABLE 33.—AVERAGE DIAMETER OF THREE LOWEST BRANCHES PRODUCED BY THREE METHODS OF PRUNING, NOVEMBER, 1929
(All measurements in centimeters)

Treatment	Lowest branch	Second branch	Third branch
Light dormant heading back and summer-tipping	.717 ± .017	.640 ± .015	.584 ± .014
Disbudding, light heading back.	.705 ± .015	.645 ± .013	.608 ± .014
Framework selected after one year's growth. . . .	.661 ± .016	.545 ± .016	.491 ± .008

checks was .574 ± .0073 centimeter. The difference between these averages is not significant, but there is a significant difference between either of them and the average diameter of the framework branches left on the summer-tipped trees, which was .645 ± .009 centimeter, and on the disbudded trees, which was .646 ± .008.

Another way in which balance can be determined is by the percentage of laterals which could be left without heading back. Since heading back was for the purpose of preserving the central leader as well as to balance the lower framework, this figure will roughly indicate the balance secured within the entire tree, including balance between the lower and upper parts. In the trees which had received slight dormant heading back and summer-tipping in the first year 83 percent of the laterals on the branches left were not headed back in the following year. On the trees headed back lightly and disbudded the corresponding figure was 84. On the trees not pruned at all the first year 92 percent of the laterals chosen for the permanent framework were left unpruned. As far as could be told, good balance had been secured by all of the methods.

The effect upon balance of the processes employed in this experiment is therefore quite different from the effect produced by the con-

ventional strong cut. The experiment does not bear out the common conception, however, that a growth of weak laterals results just back of a weak cut with no growth lower down (see Fig. 28). The results

FIG. 37.—APPEARANCE OF UNPRUNED TREES

This Duchess, photographed in June of the third season after planting, has not been pruned with the exception of the removal of vigorous growths which started from below the point where the head was desired. The lower framework branches are not being outgrown by those higher up. This tree shows the effect of the wind, a serious factor in training young trees on exposed sites.

of the three treatments on the diameters of the three lowest branches are brought together in Table 33.

That the lowest selected lateral originating at the greatest distance from a light heading-back cut made the most growth, followed successively by the two above it, is shown in Table 33. This is in marked contrast to the effect of a severe cut. This relation seems to hold in

each variety, altho there is considerable variation from tree to tree. On the average, the three lowest branches on each tree are fairly uniform in diameter, and the variation with height is least among the disbudded trees. Trees entirely unpruned are not included in Table 33. In these trees, however, there was no tendency for the highest branches to outgrow those lower down. An unpruned Duchess during the third season after planting is shown in Fig. 37.

FIG. 38.—TWO METHODS FOR REDUCING THE BENDING EFFECT OF WIND
Strong upper laterals have been removed from the tree on the left to reduce wind resistance. In the illustration on the right the central leader and a vigorous main branch are pulled back toward the prevailing southwest wind.

Methods and Results Third and Fourth Years

Trees were pruned as lightly as possible in the third and fourth years; only vigorously competing upright shoots were removed. The effect of wind upon the trunks and main branches of trees headed by the various methods was studied. The site of the experiment is very favorable for such observations, because it is fully exposed to the prevailing southwest winds. Because the tops of some of the most vigorous trees and some of the most vigorous branches were being bent out of position by the wind, methods for overcoming and preventing this effect of the wind were tried. These consisted in thinning out the tops to reduce the exposed surface (Figs. 37 and 38) and in tying back branches and tops already bent (Fig. 38). This was done early

in May of the fourth year (1931). Other trees not given these treatments were left as checks, so that the effect of wind in unpruned trees could be observed. The tendency toward self-correction was studied in 14-year-old seedlings which had received no pruning after the third year in the orchard.

Observations were made upon the effect of pruning treatments on the angles between the trunk and the main branches, since the earlier plantings had shown that in severely pruned trees the angles decreased.

The indications to date are that thinning out the tops after all of the framework branches are established will overcome the bending effect of the wind upon the trunks. Tying has an immediate effect when performed early in the growing season, but badly bent branches or tops may need to be retied repeatedly in succeeding seasons. Among unpruned trees, where the growth of individual branches was less vigorous, treatment to correct bending among individual branches was less frequently necessary than among pruned trees; the trunks, however, were not less subject to bending. It was clear that bending was the result of succulent growth and the exposure of large leaf surfaces to the wind.

The observations in older trees indicate that the tendency toward self-correction is strong. Branches on the southwest sides appear to overcome the bending effect of the wind naturally, even if the trunk is inclined strongly away from the wind. Since on exposed sites the wind is a factor in all types of pruning, its effect should be discernible in most mature orchards if it were not naturally overcome.

As in the earlier tests, vigorous main branches gradually acquired a more upright direction and their angles with the trunk decreased. That the decrease will ever result in the inclusion of bark in the crotches now appears in most case to be unlikely.

Summary of Results Obtained in Third Planting

1. Transplanting without heading back, and with very light heading back, was successful.

2. Light heading back did not result in the suppression of laterals from the lower part of the whip.

3. Disbudding whips that had been lightly headed back and summer-tipping the central leaders of trees that had been similarly pruned both produced at least two, and usually more, laterals that could be used for the permanent framework within the first year.

4. By the end of the second growing season, an average of at least four good laterals, which could be used for framework branches,

had been produced by a combination of light heading back and summer-tipping, by light heading back and disbudding, and by trees entirely unpruned the first year.

5. Disbudding to groups of buds, light dormant heading back and summer-tipping, and the selection of branches after one year on unpruned whips, all resulted in trunk growth less than that of the checks, but there were no constant differences among the treatments.

6. Variability among individuals was again the most important factor, and was not reduced by the pruning treatments employed.

7. Laterals developed the first year as secondaries from the central leaders of certain varieties without heading back were important as a source of permanent branches.

8. Branches produced by all three methods of pruning were well spaced, left the trunk at good angles, and took an upright direction.

9. Balance within the framework and, so far as could be foreseen, between the lower and upper framework, had been secured by the three methods of pruning.

10. Very little heading back was needed to maintain balance.

11. In contrast to the effect of a strong heading-back cut, which produces the most vigorous branches just back of the cut, the lowest branch back of a weak heading-back cut was, on the average, the longest.

12. It was possible to select a much better set of branches, considering as a whole the factors of size, angle, direction, vertical spacing, and uniformity, from the pruned trees than it was from the unpruned trees.

13. There was a tendency for vigorously growing trunks and branches to be bent toward the northeast by the prevailing southwest wind. Bending was the result of succulent growth and the exposure of large leaf surfaces to the wind.

14. Tying branches and trunks was a successful corrective for bending, but retying during successive growth periods may be needed.

15. Thinning out the tops after the main framework was established appeared to be a successful method for correcting bending in the tops.

16. Light pruning appeared to be a practical method for preventing excessively succulent growth and bending in the permanent branches.

17. The angles between the trunks and strongly growing permanent branches decreased, but only rarely to a degree which would be likely to cause the tree to break down.

SUMMARY AND CONCLUSIONS

1. A period of unprofitable productivity in the old age of the commercial orchard averaging fifteen years is reported by growers. It varies with the orchard and the grower more than with its location.

2. In commercial orcharding in Illinois longevity is not considered in selecting varieties.

3. Growers attribute death to various causes, but do not realize the part that pruning plays directly or indirectly.

4. Old age in apple trees is the inevitable result of the complexity of the organism, and is to be attributed to a change in structural relationships.

5. Wounds are a very important factor in death and in the initiation of the unprofitable period.

6. These wounds are often directly attributable to the way in which the tree was headed.

7. The central-leader type of tree has been the expressed preference of Illinois growers. Nevertheless most of the heads in Illinois commercial orchards are vase shaped.

8. The methods now in common use produce vase-shaped trees and no modified central-leader trees; central-leader trees are produced only accidentally.

9. The poor heads in trees that are now mature are to be attributed to the severe heading-back cut given the young tree when it was a whip.

10. Possibilities of new methods of pruning have been suggested in the past but have not been given the attention that they deserve.

11. The framework of the mature tree does not come to a permanent equilibrium. More and more framework branches are lost as the tree grows older, until finally the typical mature tree has only two or three.

12. An effort should be made to produce the type of framework in which equilibrium will be maintained as nearly as possible, especially in which equilibrium will be maintained late in the life of the tree, when wounds are likely to do the most damage.

13. In forming the framework, very narrow angles and the excessive development of one main branch are to be avoided. These factors lead to the splitting down of the head.

14. Ridging and consequent creasing are preliminary to trunk splitting in some varieties but not in others.

15. In case a number of branches arise at one point, groups are likely to be produced, that act as single branches.

16. A vertical spacing of branches is desirable to avoid "smothering

out" the central leader. Vertical spacing is also a necessary condition in the modified central-leader tree, which, except for this, resembles the vase-shaped tree in its coordination of branches.

17. There is no indication that the modified central-leader type is not suitable to all varieties.

18. The problems of training are greatly simplified by starting the framework branches by disbudding to groups of buds. The dominance of the upper branches and the sharp forks resulting from the severe heading-back cut are thereby avoided. Uniformity is secured among the main branches which are subordinate to the central leader, and the method is well adapted to producing the modified central-leader type.

19. Other methods of training are suggested which do not depend upon heading back the whip severely.

RECOMMENDATIONS

Of the three new methods of heading reported,—disbudding, summer-tipping, selection of framework one year after planting, — disbudding to groups of buds is considered the best and is therefore recommended in preference to the others.

To train trees by the disbudding method, the following steps are recommended. These recommendations are based not only upon the data recorded above, but also upon incidental observations made as the study progressed.

(First Season)

1. Use vigorous one-year whips, which have been allowed to dry out as little as possible before planting.

2. The whips should be inclined very slightly toward the prevailing wind. Tipping them too far, so that that side becomes distinctly an underside, discourages shoot development in that direction, and the shoots that start are likely to grow into and thru the tree.

3. Just before growth starts, disbud the whips to groups of three or four consecutive buds. Leave groups at each height where a framework branch is wanted. The interval between groups should be about 8 inches from center to center. The buds should be removed with a sharp knife.

4. The whip should not be headed back.

5. Let the tree grow undisturbed thruout the entire growing season.

(Second Season)

6. At the beginning of the second growing season, make a selection of one branch at each height for the permanent framework. Select for

uniformity in diameter and length (to secure balance), for proper direction (location in a spiral), and for an angle suitable to the variety. The laterals left on drooping varieties, like the Jonathan and Winesap, should have a more upright direction than on upright varieties, like the Transparent and Delicious. In any case the angles should not be so close that bark will later be caught in the crotches. Proper angles will usually fall between 20 and 45 degrees from the perpendicular.

7. Remove or head back lightly all vigorous laterals not to be left for the permanent framework. Their removal is sometimes the better treatment, because it establishes the permanent framework branches at once and avoids the necessity for securing dominance gradually. It also avoids the difficulties which result from heading back. However, pruning very vigorous trees heavily at this time induces such succulent growth in the laterals left for the permanent framework that they may be bent out of shape by the wind, and in the most upright varieties the angles between some of the framework branches and the trunk may become too acute. Short horizontal laterals, which will not compete with those selected for the framework, should be left to increase the diameter of the trunk as much as possible. It is not necessary or desirable to head back the laterals to be left permanently. If they are let alone, they will become branches coordinate with the central leader, an important step in the easy development of the modified central-leader tree.

(Third Season)

8. At the beginning of the third growing season, replace any poor laterals with better laterals which may have developed from buds that remained dormant or from shoots that grew poorly during the first season. This may be necessary on poorly grown trees, on trees that have been mistreated before planting, or on trees that have been poorly planted. If necessary, higher laterals may be selected for the permanent framework at this time.

9. Remove any vigorous misplaced shoots. Let all other growth remain.

10. It is seldom necessary to head back for balance, but occasional laterals can be removed for this purpose.

11. Laterals in the upper part of the tree should be thinned out if the tree tends to become top heavy. The central leader, however, should not be removed or headed back because it is to be used as the highest branch in the main framework. It is to be kept equal in size with those lower down, preferably by removing laterals.

(Fourth and Following Seasons)

12. Prune as little as possible. By this time the three to five main framework branches should have established themselves, and only an occasional vigorous new shoot should need removal. It may be necessary to remove a very few branches to keep the tree balanced. Since the central leader is to be the highest main framework branch, coordinate in size with those lower down, its vigor should be reduced, if it tends to outgrow the lower branches, by removing some of its laterals.

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